TM 4-225

WAR DEPARTMENT

~~U. S. Dept. of Army~~

TECHNICAL MANUAL

ORIENTATION

July 15, 1941

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TECHNICAL MANUAL

AIR NAVIGATION TABLES

CHANGES No. 1 } WAR DEPARTMENT, WASHINGTON, October 17, 1942.

TM 1–208, June 5, 1942, is changed as follows:

TABLE III

LOG SINES, TANGENTS, AND SECANTS

1. General.

* * * * * * *

Example 2.—Given Log tan θ=**.09447** or **10.09447**−10, find θ.

Find the column headed "Tangent" that contains **10.09447.** This will be found on the page with tangent of 51° appearing at the foot. It is then found that **10.09447** is in the row containing 11′ in the right-hand minute column. Therefore θ is found to be 51° 11′.

[A. G. 062.11 (10–12–42).] (C 1, Oct. 17, 1942.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:
J. A. ULIO,
Major General,
The Adjutant General.

490919°—42

U. S. GOVERNMENT PRINTING OFFICE: 1942

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TECHNICAL MANUAL } WAR DEPARTMENT,
No. 4–225 } WASHINGTON, *July 15, 1941.*

ORIENTATION

Prepared under direction of the
Chief of Coast Artillery

SECTION I

GENERAL

1. **Purpose.**—The purpose of this manual is to provide a text and reference book covering the principles of orientation.

2. **Definition.**—The term orientation as used in the Coast Artillery Corps means:

a. The accurate location of datum points and the establishment of lines of known length and direction.

*This manual supersedes TM 2160–25, December 11, 1933.

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b. The adjustment of the azimuth-indicating devices on guns and observing instruments to read the known azimuth when the axis of the line of sight is pointed at that azimuth.

3. Application.—In its application to artillery, the term orientation includes the following:

a. The determination of the meridian for the measurement of azimuths.

b. The determination of the coordinates of the directing point, observing stations and spotting stations for a battery.

c. The determination of the length and azimuth of base lines and director offsets.

d. The establishment of such reference and datum points as may be necessary.

4. Unit commanders and reconnaissance officers.—*a*. Unit commanders are charged with the responsibility for correct orientation of the elements of their commands. However, each commander is provided with a staff officer trained as a specialist in orientation and who is charged with the proper execution of orientation as well as other reconnaissance functions. This officer is called the reconnaissance officer.

b. The battalion reconnaissance officer is charged with the duty of determining the coordinates and an orienting azimuth at all battery observing stations and directing points, and at such battalion observing stations as may be directed.

c. The battery reconnaissance officer, who is also the battery range officer, is charged with the duty of orienting his plotting board, observing instruments, and any fire-control instruments located at the battery position. The battery executive is charged with the duty of orienting the guns of the battery.

5. American Nautical Almanac.—*a*. Solution of the typical problems which confront the orientation officer will be found in this manual and in TM 5-235. Solution of problems in azimuth determination by astronomical observations have been incorporated in this manual using Greenwich hour angles extracted from the American Nautical Almanac.

b. The use of the American Nautical Almanac, which is one-third the bulk and one-fifth the cost of the Ephemeris, is considered more expeditious than the Ephemeris, because the Almanac includes the calculations of the Greenwich hour angle of the heavenly bodies for every day of the year. The use of the Greenwich hour angle taken directly from the Almanac eliminates the calculation of Greenwich

sidereal time and the right ascension of the star, and the equation of time for the calculation of Greenwich apparent time.

6. References.—*a.* The following publications will be required by the orientation officer in his computations of azimuths and grid coordinates:

(1) American Nautical Almanac (current year) or
(2) American Ephemeris (current year).
(3) TM 5-235.
(4) TM 5-230.
(5) TM 5-236.

b. Other publications listed in appendix II will be of material assistance in grasping the fundamentals and application of orientation.

Section II

INSTRUMENTS

7. General.—The principal surveying instruments with which an orientation officer should have good working knowledge are—

Transit and its verniers.
Compass.
Plane table.
Telescopic alidade.
Level and level rod.
Stadia rod.
Steel tape.

8. Transit.—*a.* The transit is the most useful and universal of all surveying instruments. Besides measuring horizontal and vertical angles, which is its primary function, it will also determine bearings by means of the compass, do leveling by means of the long bubble under the telescope, and measure distances by means of the stadia wires.

b. Detailed directions for the care, use, and adjustment of surveying instruments, together with step-by-step descriptions of practical methods applicable to their uses in military surveys is contained in TM 5-235.

9. Plane table and alidade.—*a.* The plane table is a surveying instrument consisting of a drawing board mounted on a tripod, and

an alidade which is placed on the board and moved about at will. It is used in the field for projecting the lines and points of a survey directly on the drawing, thus eliminating the measuring of horizontal angles and their subsequent plotting from notes by the use of a protractor. It thus makes a graphic record of a survey. In a warfare of movement, where time becomes a very important factor, the plane table is frequently used to determine topographical data for motorized artillery. However, for large caliber long-range guns, the determinations are not sufficiently accurate and more precise instruments should be used. A plane table with a telescopic alidade is shown in figure 123, TM 5-235.

b. General instructions for the use and adjustments of a plane table are contained in paragraphs 138 to 152, TM 5-235.

Section III

MILITARY MAPS

10. General.—*a*. A map is a small scale representation of a portion of the earth's surface projected on a plane. Since the surface of the earth is a sphere, it is obvious that it is impossible to represent any large portion of it on a plane without a certain amount of distortion. Since a spherical surface cannot be reproduced as a plane with absolute accuracy, the representation is approximate only, with characteristics dependent upon the methods of construction employed.

b. There are many types of map projections, some accurate in one respect, some in another, but none accurate in all. It is important that a reconnaissance officer have a general knowledge of their characteristics and know where to get more detailed information when desirable, in order that he may intelligently make use of available nonstandard maps. All available maps of any theater of operations will probably be used by the military forces. Certain types, however, have been found to be best adapted for specific military purposes, and maps are prepared as far as practicable to serve these needs.

11. Classification.—Maps are classified according to scale. The use of the various types of maps depends upon the character of the information to be obtained from a study of the detail of the map (see par. 30, FM 30-20).

a. Intermediate scale maps.—The Strategic Map of the United States, scale 1:500,000, is an intermediate scale map and is intended for planning strategic operations, including troop movements, concentration and supply.

b. Medium scale maps.—The United States Geological Survey map, scale 1:62,500, is an example of a medium scale map and is intended for tactical and administrative studies by units of the size of a corps or regiment. This map contains many topographical features which are advantageous in the study of terrain details when planning a campaign.

c. Large scale maps.—Maps of large scale, normally not greater than 1:20,000, are for the technical and tactical battle needs of the Artillery and Infantry. The scale of the battle map is 1:20,000.

12. Map substitutes.—In order to provide a map suitable for technical military use, experiments have been conducted in rapid map making using aerial photographs.

a. The vertical aerial photograph is a valuable instrument for conveying topographical information.

(1) It possesses in picture a wealth of detail which no map can equal.

(2) It possesses accuracy of form.

(3) With freedom of flight, an aerial photograph may be prepared in a short time and reproduced in quantity by lithography.

(4) It may be made of an area which otherwise is inaccessible because of either physical or military reasons.

b. The vertical, aerial photograph is inferior to a good map in the following respects:

(1) Important military features are sometimes obscured or hidden by other detail.

(2) Neither absolute position nor absolute elevation can be obtained.

(3) Relative relief is not readily apparent.

(4) Displacements of position caused by relief and camera tilt usually do not permit the accurate determination of distance or direction.

c. For definitions and descriptions of map substitutes, see paragraph 90, TM 5–230.

d. Battle maps.—The ideal battle map would include the most accurate topographic map supplemented by the most recent aerial photographs. At the present time the best known battle map is one which gives control and detail by photogrammetric methods. The multiplex and stereo-comparagraph are used to add contours, grid

lines and battle positions to the map as rapidly as possible to produce the finished battle map.

13. Aerial photographs.—*a*. In addition to the information which may be secured from a map, an aerial photograph portrays a wealth of detail such as communication centers, bridges, railways, and bivouac areas which might provide adequate cover for concealment of troops. They offer a valuable accessory for fire control because the photograph gives a detailed representation of the terrain as it appears at a particular time.

b. For the role which is played by aerial photography in military intelligence and the methods of preparing photomaps and the interpretation of aerial photographs, see TM 5-230, FM 30-20, and FM 30-21.

SECTION IV

PROJECTIONS

14. General.—Theoretically, the earth is an oblate spheroid in shape; a figure formed by rotating an ellipse around its shorter axis. Because of the continents and islands, the actual surface is slightly irregular. The distance from the center of the earth to a point at sea level on the equator is 3,963.3 statute miles and the distance from the center of the earth to either of the poles at sea level is 3,950 statute miles. This difference is so slight that the earth may be mentally pictured as a round ball or sphere which rotates on a line or axis passing through its center. The imaginary intersections of this axis with the surface of the earth are called the North and South Poles. Circles of the earth's surface, cut by imaginary planes passing through the poles, are called meridians of longitude (fig. 1). Circles cut by imaginary planes at right angles to the axis are called parallels of latitude. The parallel midway between the poles is called Equator and divides the earth in the Northern and Southern Hemispheres.

15. Geographic coordinates.—In order to define positions on the earth's surface it is necessary to have fixed reference planes and surfaces. The surface of mean sea level has been adopted as the surface of zero altitude. The meridian passing through Greenwich

Observatory, near London, is usually taken as the reference meridian from which longitude is measured in degrees, minutes, and seconds halfway around the globe, positive to the west and negative to the east. The Equator is taken as the reference parallel from which latitude is measured in degrees, minutes, and seconds to the poles, positive to the north and negative to the south of the Equator. Geographic coordinates (latitude and longitude) are used to designate

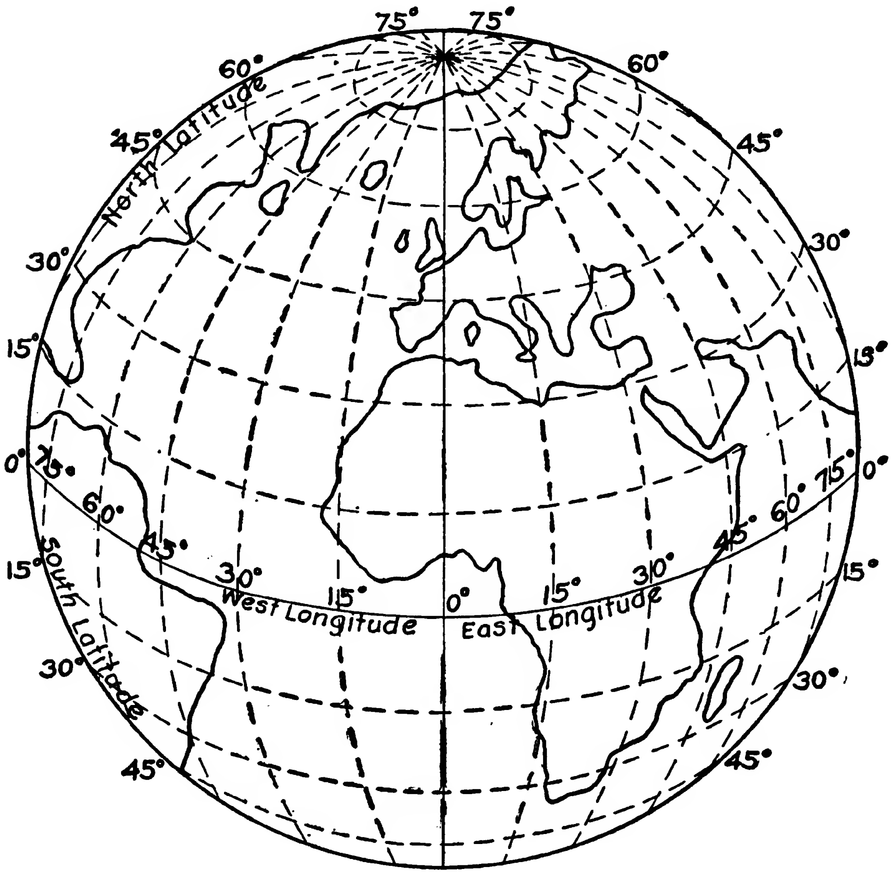

FIGURE 1.—Globe showing meridians and parallels.

the location of points on the earth's surface by reference to these fixed initial planes (see fig. 1). While the algebraic signs of the latitude and longitude show whether they are north or south, east or west, the letters N, S, E, W are usually used, being placed after the figures. For example, the approximate geographic coordinates of the Capitol at Washington are, latitude 38°53′23″ N., longitude 77°00′34″ W. Further information regarding latitude and longitude may be found in paragraph 57, TM 5-230.

16. Map projections.—*a.* No map is accurate in every detail; if it is accurate in an east and west direction there is distortion north and south, and vice versa. There are many methods of representing a part of the earth's surface approximately and, in determining a method of projection, it is necessary to select one that will best meet the requirements the map is to fulfill. The most desirable features of a good map are as follows:

(1) Areas should be represented in their true shape.

(2) Areas should retain their true relative size.

(3) Distances on the map should keep a constant ratio to the same distances on the ground.

(4) Direction of lines and the size of angles on the map should be preserved.

(5) Great circles should be represented by straight lines. No one of these properties can be secured without sacrificing some of the others. In determining the type of projection to be employed, it is therefore necessary to decide which features most nearly satisfy the conditions under which the map is to be used.

b. From a military standpoint, it would be desirable to have a projection that would give a minimum of distortion in the representation of distances and angles at all parts of a map. It is customary in constructing maps to project the portion of the earth's surface under consideration to a cylindrical, conical, or other surface which is capable of being developed into a plane; or to plot it to some system of developed lines which on a plane surface bear homologous relation to the latitude and longitude lines of the earth's surface. It is in this latter category that military maps belong. Such a system of lines designed for the purpose of constructing a map on a plane surface is called a projection.

17. Types of projections.—The most important types of map projections are:

a. (1) *Conformal projections*, which preserve the shape of the small geographic features at the expense of a constantly changing scale and which show the meridians and parallels intersecting at right angles. The term "conformal" used in connection with a projection means that any very small figure upon the earth is represented by a similar small figure upon the map. This entails two qualities. For short distances at any place the scale is the same in all directions, and the angle between two curves upon the earth is preserved in their representations upon the map. In consequence of this, the *azimuth of lines on the map are the same as upon the earth.*

(2) An example of this type of projection is the Lambert conformal conic projection which is explained in paragraph 48.

b. (1) *Cylindrical projections*, which consist of the projection of the earth's surface on a cylinder tangent to the earth at the Equator, either by projecting the earth's radii on the cylinder or projecting planes parallel to the plane of the Equator on the cylinder. Both methods result in great distortion and have to be modified in practice.

(2) The Mercator and transverse Mercator projections are examples of this type.

c. (1) *Conical projections*, which are projections of the radii of the earth on a cone tangent to the earth at a certain latitude.

(2) A familiar type of conical projection is the *polyconic* projection which has been adopted for the production of military maps and upon which is superimposed the military grid system. Polyconic projections are explained in TM 5-235.

d. Equal area projections, which keep the ratio of areas constant at the expense of correct shape.

e. Azimuthal projections (sometimes called zenithal), which keep correct directions of all points on the map with respect to the center of the map. This type is used principally for navigation purposes.

f. Perspective or geometric projections, which consist of the direct projection of points on the earth's surface by means of straight lines drawn through them from some point, usually the center of the earth. These lines are projected on a plane tangent to the earth at the center of the area to be projected.

g. Gnomonic projections, in which the radii of the earth are projected on a tangent plane. Great circles appear as straight lines on this projection. Distances, areas, and shapes are greatly distorted. Its only value is in connection with navigation.

h. Bonne equal area conic projection.—The Bonne system of projection was the standard military map of France before the World War, but due to great distortion, it has since been discarded and will probably seldom be encountered.

i. Albers conical equal area projection.—The Albers projection is the most satisfactory projection for military purposes. The United States Board of Surveys and Maps has recommended that this type of projection be used by any bureau that may hereafter construct a map of the United States. It has not, however, been adopted as standard for any military.

j. Description.—A description of the three principal types of projections; that is, the polyconic, conic, and Mercator, are found in section XI, TM 5-230.

18. Lambert conformal conic projection.—*a.* The Lambert conformal conic projection is a secant cone type of projection which intersects the earth at two parallels of latitude. Along these two parallels the scale is exact; between them the scale is slightly shortened and outside of the parallels the scale is somewhat too large. This gives a balance of scale over the whole projection and makes it possible to cover a wide extent of latitude with minimum distortion. Tables of scale variations have been computed for every minute of latitude so that these variations may be taken into consideration in any computations and full allowances made for them.

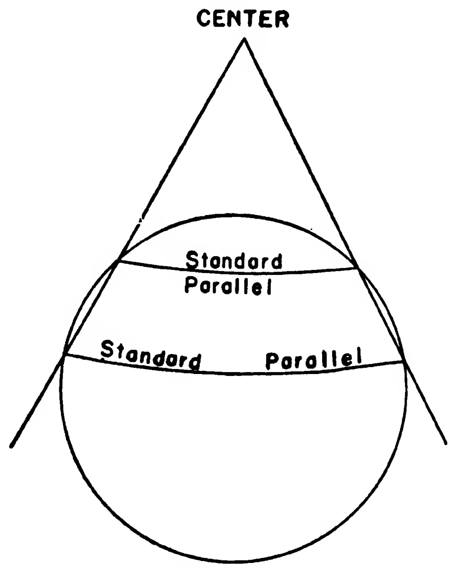

FIGURE 2.—Sphere with intersecting cone for Lambert projection.

Thus computation of distances may be very accurate in all parts of the projection.

b. When using grid coordinates taken from a Lambert projection for the computation of azimuths and distances, it is not necessary to make any correction for magnification of scale.

c. The meridians will all intersect at a point at the apex of the cone. When the conical surface is split along an element, it can be unrolled in a plane and the parallels become arcs of concentric circles. When the conical surface is developed in a plane, it forms a sector of a circle.

d. This intersecting type of projection provides a better map for certain purposes than does a tangent cone projection because of its uniformity of scale.

Section V

COORDINATES AND GRID AZIMUTHS

19. Convergence of meridians.—*a.* The distance between two adjacent meridians is greatest at the Equator and gradually decreases in a north-or-south direction until it becomes zero at the two poles. The angular amount by which meridians approach each other is called the convergence of the meridians. For example, the convergence of the meridian of longitude 72° with that of longitude 73° at the pole is 1°; but at the Equator all meridians are parallel and the convergence is zero. It is thus apparent that the amount of convergence of meridians is a function of the latitude.

b. The formula for the amount of the convergence of the meridians between any two points is: Convergence (in seconds of angle) equals difference in longitude of the two points (in seconds of angle) times sine of the mean latitude of the two points.

c. The azimuth of a line *BA* is commonly called the back azimuth of a line *AB*. The back azimuth of a line differs from the forward azimuth by 180° plus or minus the convergence of the meridians through the two points at the ends of the line. The true back azimuth and the true forward azimuth of a line differ by exactly 180° only when the line is due north and south or along the Equator.

d. Further explanation of azimuths and bearings may be found in paragraph 76, TM 5–235.

20. Military grid system.—*a.* In order to avoid difficulties and inconveniences inherent to the spherical grid, a special rectangular grid has been devised for use on military maps.

b. For purposes of superimposing the rectangular grid, the United States has been divided into seven zones, each 9° of longitude wide. In the polyconic projection of each zone the central meridian is the *Y* axis of that zone and the parallel of 40°30′ latitude is the *X* axis for all

zones. With the intersection of the X and Y axes in each zone as an origin, a system of lines parallel to each axis is drawn, forming a network of squares on the map. The distance to each axis is drawn, forming a network of squares on the map. The distance between grid lines, in even thousands of yards, varies from 1,000 to 100,000 yards, depending on the scale of the map. To avoid the use of negative coordinates, the geographic origin of the grid system for each zone is given the coordinates: $X=1{,}000{,}000$; $Y=2{,}000{,}000$.

c. To avoid the confusion which would result when operating in areas lying in two adjacent zones, it was decided to have zones overlap one another by 1°. The designation of zones, their central meridians, and limiting meridians are shown in the following table:

Designation (zone)	Central meridian	Limiting meridians			
United States:	°	°	′	°	′
A	73 West	68	30	77	30
B	81 West	76	30	85	30
C	89 West	84	30	93	30
D	97 West	92	30	101	30
E	105 West	100	30	109	30
F	113 West	108	30	117	30
G	121 West	116	30	125	30
Foreign possessions:					
Canal Zone	81 West				
Hawaii	158 West				
Philippine Islands	122 East				

The zones are shown graphically in figure 3.

d. The military grid appears registered on gridded maps in two series of parallel lines at right angles to each other. The central meridian of the overlap between adjacent grid zones is the dividing line between the zones. Any map which falls within the 1° overlap between grid zones always shows in solid black lines the grid of the zone to which the map pertains. The grid of the adjacent overlapping zone may also appear registered by means of grid interesections (small crosses) on the face of the sheet and ticks around the border lines. The scheme is useful in effecting transition of data from one zone to another. The lines of the overlapping zone when needed may be struck in by simply joining the registration points. Since the grid lines of each zone are all parallel to the central meridian of the zone and since meridians converge to the poles, the lines of overlapping grids will always cross at distinct angles.

e. The distance of each north and south grid line, grid east of the zero point or origin of coordinates, is marked in thousands of yards along the south border of a gridded map. The distance of each east and west grid line, grid north of the zero point or origin, is marked in thousands of yards along the west border of a gridded map. The numbers which identify the north and south grid line and the east and west grid line which intersect at or nearest to the southwest corner of a gridded map are written out in full in yards. In marking all other grid lines, the digits common to the sheet may be omitted. When the grid of an overlapping zone appears registered by ticks and grid intersection on a map, the ticks of the north and south and east and west grid lines, respectively, which intersect at or nearest to the southeast corner, are marked in full to yards. No other grid lines of the overlapping zone are marked.

f. The system of north and south grid lines on a gridded map is referred to as the *Y* lines and the system of east and west grid lines is referred to as the *X* lines. All *Y* lines are parallel to the central meridian of the grid zone in which the map falls. All *X* lines are at right angles to this central meridian. The base directions established by the *Y* lines are known as "grid north" and "grid south." The base directions established by the *X* lines are known as "grid east" and "grid west."

g. In any system of rectangular coordinates, if the abscissas *X* and ordinates *Y* of two points are known, the determination of the length and direction of the line joining them requires only the solution of a right triangle. Likewise, in such a system the position of a point may be determined if the distance of the point from two reference lines intersecting at right angles is known. The two distances which locate the point are measured parallel to the horizontal and vertical axes and are known as the "*X*" and "*Y*" coordinates, respectively.

h. A complete explanation of the Military Grid System with tables giving grid coordinates of the intersection of every 5′ of latitude and every 5′ of longitude within the United States and with formulas for the conversion of geographic coordinates into grid coordinates and vice versa, may be found in Special Publication No. 59, Grid System for Progressive Maps in the United States, United States Coast and Geodetic Survey. Tables for converting geographic into grid coordinates in the vincinity of the Canal Zone have been prepared by the Corps of Engineers. However, no tables are available for this conversion in Hawaii or the Philippine Islands and it is therefore necessary to compute the grid coordinates for given posi-

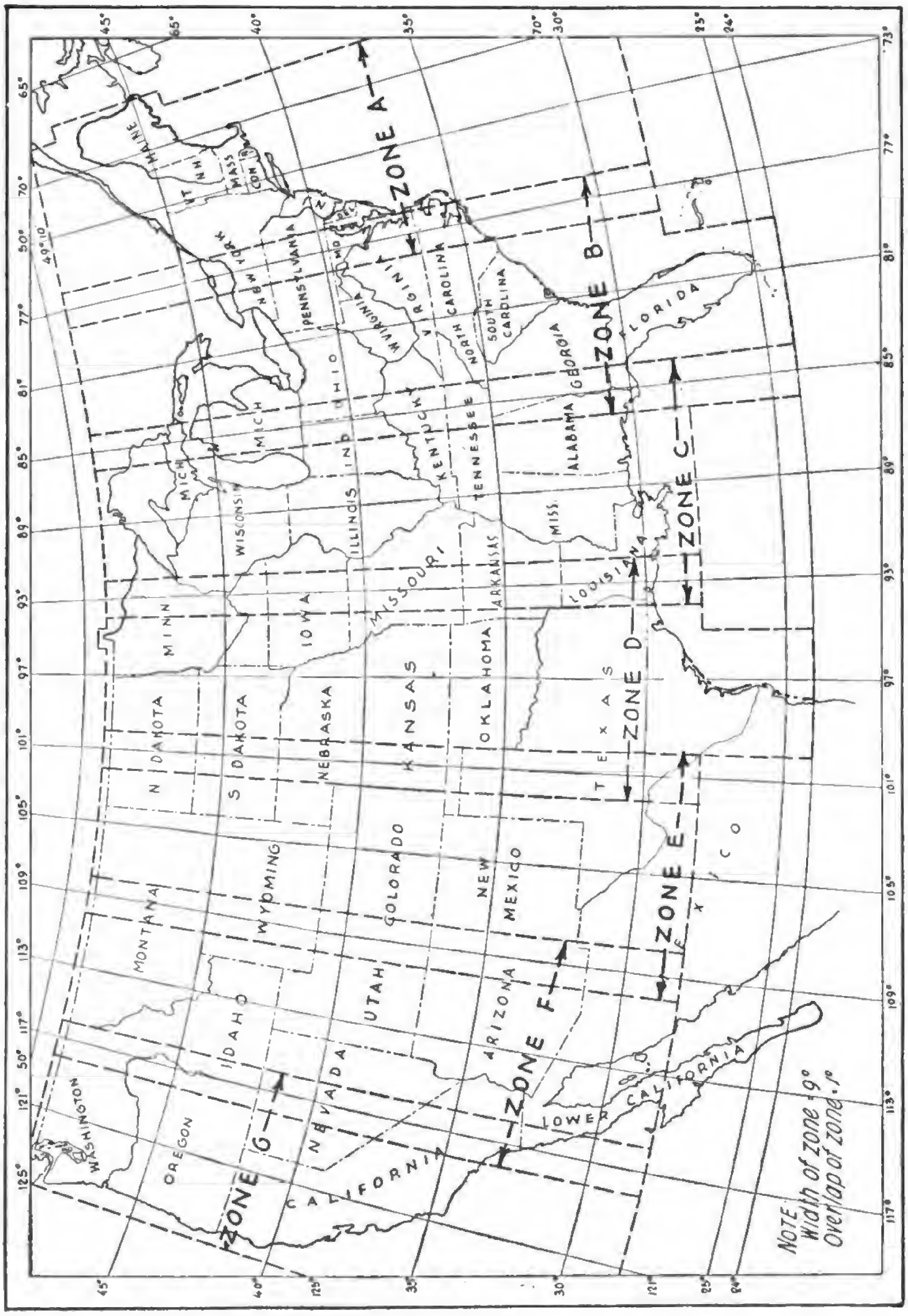

FIGURE 3.—Grid zones for fire-control maps.

tions. Special Publications Nos. 5 and 8, United States Coast and Geodetic Survey, provide the necessary data for this computation.

i. In this manual the term "military grid coordinates" refers to those coordinates computed or scaled from the zone polyconic type of projection.

j. The term local plane coordinates refers to the coordinates computed from one of the types of projections outlined in paragraph 21.

k. Thus it is seen that the term military grid coordinates supersedes the old term standard grid coordinates. It is considered that the word standard was erroneously used and was misleading.

21. Local plane coordinates.—*a.* Although the military grid coordinate system is applicable to all parts of the United States, there may occur situations where a local coordinate system for the area is desired. In such a case it is necessary to establish a system of *local plane* coordinates. These may be computed from several types of projections such as:

(1) Local polyconic projections.
(2) Lambert conic projections.
(3) Transverse Mercator projections.

An important distinction between these systems and the military grid system is that the point of origin of any local plane system is some local point. This point is ordinarily given grid coordinates, such as $X=100{,}000$ and $Y=200{,}000$. A true north-south line is determined through this point and a grid system with resulting rectangular axes is superimposed on the map.

b. In response to the demand from engineers all over the country, systems of plane coordinates for each State of the Union have been computed by the United States Coast and Geodetic Survey. No one system was applicable since variations in scale are inevitable. It is of great advantage to adopt a scheme that will give definite scale values in certain directions. This will lead to the adoption of one of the conformal types of projections.

c. After due consideration, the Coast and Geodetic Survey decided to employ—

(1) The Lambert conformal projection with two standard parallels for States with their greatest length in an east-and-west direction; for example, Tennessee; and

(2) The transverse Mercator projection for States with their greatest extent in a north-and-south direction; for example, Mississippi. Both of these projections are conformal and each is especially suitable for the States in which it is employed.

d. A list of the States showing their respective grid systems appears below. Lithographed copies of the plane coordinate tables for certain areas bounded by parallels of latitude in these States may be secured by application to the Director of the United States Coast and Geodetic Survey, Washington, D. C.

Lambert system

1. Arkansas
2. California
3. Colorado
4. Connecticut
5. Iowa
6. Kansas
7. Kentucky
8. Louisiana
9. Maryland
10. Massachusetts
11. Minnesota
12. Montana
13. Nebraska
14. North Carolina
15. North Dakota
16. Ohio
17. Oklahoma
18. Oregon
19. Pennsylvania
20. South Carolina
21. South Dakota
22. Tennessee
23. Texas
24. Utah
25. Virginia
26. Washington
27. West Virginia
28. Wisconsin
29. Long Island
30. Nantucket and Martha's Vineyard

Transverse Mercator system

1. Alabama
2. Arizona
3. Delaware
4. Georgia
5. Idaho
6. Illinois
7. Indiana
8. Maine
9. Michigan
10. Mississippi
11. Missouri
12. Nevada
13. New Hampshire
14. New Jersey
15. New Mexico
16. New York
17. Rhode Island
18. Vermont
19. Wyoming

Both systems

Florida

e. Examples will be given illustrating the methods of converting geographic coordinates to plane coordinates on the *Lambert projection;* and converting geographic coordinates to plane coordinates on the *transverse Mercator projection.*

f. Should it be necessary to convert plane coordinates of one type of projection to another, model computations may be found in Special Publications 194 and 195 of the Coast and Geodetic Survey and in TM 5–235.

g. In the Harbor Defenses of Chesapeake Bay the system of rectangular coordinates is based on a Lambert projection. This uses parallels 36°38′30″ and 37°21′30″ of latitude for the east-west control lines along which the scale is true, and the 76th meridian as the center of the zone with zero azimuth south. A survey has been completed and computations made by the Coast and Geodetic Survey with a precision of second order triangulation, which is the standard precision required for fire control determinations.

h. It is very important to note at this time that when using local plane coordinates computed on Lamberts conformal conic projection (sometimes called the secant cone projection), *it is not necessary* to correct the Δy map measurement for magnification of scale, because of the very small distortion in this type of local projection.

22. Methods of obtaining military grid coordinates.—There are several methods of obtaining the military grid coordinates of a point. They are—

a. The conversion of the geographic coordinates (latitude and longitude) to military grid by interpolation in Special Publication No. 59, United States Coast and Geodetic Survey, subject: "Grid System for Progressive Maps in the United States." The tables in this text show the grid coordinates in yards of the intersection of each fifth-minute of longitude with each fifth-minute of latitude within the whole area covered by the grid system. Special military maps based on this grid system are to be 10,000 yards long in an east-and-west direction and 6,000 yards deep in a north-and-south direction.

(1) A table of grid coordinates in yards for the intersection of each minute of longitude with each minute of latitude has been computed by the United States Coast and Geodetic Survey and any completed sections of this table will be furnished in manuscript form upon request.

(2) Linear or straight interpolation for the minute intersections can be made between the x coordinate values for the 5-minute intersections in the direction both of increasing latitude and of increasing longitude without introducing appreciable errors. Likewise such interpolations can be made between the y values in the direction of increasing latitude, but in the direction of increasing longitude an error as great as one yard may be introduced in the value of y by linear interpolation.

(3) If the work in hand is such that this error is appreciable, the y values should be interpolated in the longitudinal direction in the following manner:

(a) The departure of the parallel from the x grid line tangent to it at its intersection with the central meridian should be interpolated as the squares of the distances out from the central meridian. For example, if we wish to interpolate the y value for latitude 37°05′ and longitude 75°02′, we should proceed in the following manner:

$$\left.\begin{matrix}37°05' \\ 73°00'\end{matrix}\right) y = 1{,}585{,}214.0$$

$$\left.\begin{matrix}37°05' \\ 75°00'\end{matrix}\right) y' = 1{,}587{,}260.3$$

$$y'' = y' - y = 2{,}046.3$$

75°00′ is 2° or 120′ out from central meridian.

75°02′ is 2°02′ or 122′ out from central meridian.

$$y \text{ for } 75°02' = 1{,}585{,}214.0 + \left(\frac{122}{120}\right)^2 \times 2{,}046.3 = 1{,}587{,}329.1.$$

Corresponding values are 1,587,329.0 from minute table or 1,587,-329.9 by linear interpolation.

(b) After the x and y coordinates have been interpolated along two contiguous 5-minute parallels, as explained above, then straight interpolation along the meridian between these values can be made for intermediate parallels.

b. The conversion of geographic coordinates to military grid coordinates by *formula* as explained in paragraph 117*f*, TM 5–235.

c. The conversion of local plane coordinates to military grid coordinates (polyconic projection), as explained in paragraph 119, TM 5–235.

d. The computation of a traverse, using several known points as a basis to determine the coordinates of an unknown point.

e. The scaling of the coordinates from a grid map.

23. Conversion of geographic coordinates to military grid coordinates.—*a.* Instructions and a model computation for the conversion of geographic to grid coordinates appear in subparagraph 117*f*, TM 5–235. This method of conversion is applicable for polyconic grid projections only, since the work is based on the tables which appear in United States Coast and Geodetic Survey Special Publication No. 59.

b. Conversion of geographic to grid coordinates for the Lambert and transverse Mercator projections appears in paragraphs 24 and 25.

24. Conversion of geographic coordinates to plane coordinates on Lambert grid.—Since the Lambert projection has been made the basis for plane coordinate systems in many states, the following example will illustrate a method of converting geographic coordinates to Lambert grid coordinates.

a. First secure from the Director, Coast and Geodetic Survey, Washington, D. C., one table for the radii values for the standard parallels included in the map and another table listing the mapping angle, denoted by θ. This is merely the longitude out from the central meridian multiplied by a constant l of the projection. Every minute of longitude has been tabulated and it is only necessary to multiply the seconds of longitude by the constant l to get the value for θ for any longitude. For a point east of the central meridian this seconds value has to be subtracted from the minute tabular value to determine the full value of θ. When west of central meridian, the two values are added together numerically to get the corrected negative value of θ.

b. The procedure for computation of plane coordinates on the Lambert grid is as follows:

Denote the longitude measured from the central meridian as $\Delta\lambda$; eastward as plus, westward as minus.

Use the table of sin θ to determine the tabular difference for each second of $\Delta\lambda$.

The value of sin θ for each minute is also given in the same table.

Take from the table the value of sin θ for any given minute and add to it the product of the tabular difference for one second and the number of seconds of $\Delta\lambda$ beyond the minutes.

To obtain the value of $2 \sin^2 \frac{\theta}{2}$, express the $\Delta\lambda$ in minutes and decimal fractions of a minute.

Square this number and multiply the result by the constant K (K will be given for each map area).

This gives the value of $2 \sin^2 \frac{\theta}{2}$ multiplied by 10^7 or with the decimal point moved seven places to the right.

To offset this factor, move the decimal point in R (which is read from the tables) seven places to the left.

The decimal point will then fall to the left of the first significant figure of R which will be nine (9).

For this operation, therefore, R will be used as 0.9.

R multiplied by $2 \sin^2 \frac{\theta}{2} \times 10^7$ gives the y'' value.

Add y'' to y' to obtain Y coordinate.

R and y' are given in the tables of Lambert values for each map area.

A constant of 100,000 yards is added to the X values to keep those coordinates positive.

c. Example of conversion of geographic coordinates to plane coordinates on special Lambert projection.

State: Virginia. Grid: Lambert. Station: Thimble Shoals Lighthouse.

		λ (Central meridian)	76°00′00.000″
ϕ 37°00′51.712″		λ	76 14 25.074
		$\Delta\lambda$(Central meridian$-\lambda$)	14 25.074
Tabular difference of $\sin\theta$ for 1″ of $\Delta\lambda$	29,177.000	$\Delta\lambda$ in min.	14.4179
Sin θ (for 14 min. of $\Delta\lambda$)	0.0024508663		
Cor. for 25.074 sec. of $\Delta\lambda$	+.0000731582	$(\Delta\lambda)^2$	207.8758
$\sin\theta$	0.0025240245	$K(\Delta\lambda)^2=2\sin^2\frac{\theta}{2}\times 10^7$	31.853
Tabular difference of R for 1″ of ϕ	33.7115		
R (for 14 min. of ϕ)	9,267,631.02	y' (for min of ϕ)	121,356.96
Cor. for sec. of ϕ	− 1,743.29	Cor. for sec. of ϕ	−1,743.29
R	9,265,887.73		123,100.26
		$y''=\left(2R\sin^2\frac{\theta}{2}\right)$	+29.51
	100,000.00		
		Y	123,129.76
$R\sin\theta$	23,387.33		
X	76,612.67		

In computing y'', move the decimal point in the R value seven places to the left to offset the factor 10^7 in the value of $K\ (\Delta\lambda)^2$.

25. To convert geographic coordinates to plane coordinates on transverse Mercator projection.—Projection tables of y values have been computed along the central meridian for every minute of latitude. These are merely the lengths along the central meridian from the latitude at which $y=0$, with the proper reduction in scale applied. With these are also tabulated the differences for each one second of latitude. These tables are used for the transformation of geographic to plane coordinates on the transverse Mercator grid, as explained in detail on pages 5 to 8, Special Publication No. 195, Coast and Geodetic Survey, "Manual of Traverse Computation on the Transverse Mercator Grid." The coordinates of a station SAKONNET,

in Rhode Island are computed on the following form as an example of the computation on this type of projection. The given geographic coordinates of this point are latitude 41°27′37.129″ N and longitude 71°11′22.621″ W. The projection table for Rhode Island gives the λ for the central meridian as 71°30′00.00″. This is the constant for this particular projection system. From this is subtracted the λ (longitude) of our station, giving $\Delta\lambda$, in this case +18′37.379″ which reduced to seconds is +1117.379″. The complete computation and tables involved are shown in detail on pages 24 to 28, Special Publication No. 193, Coast and Geodetic Survey, "Manual of Plane Coordinate Computation" and will not be reproduced in this text. Those who must make the conversion of geographic coordinates to local plane coordinates are advised to secure a copy of the above manual as they will find it very helpful in this type of work. Many examples have been worked out in detail for the various states and illustrate problems involving the several types of projections.

26. Grid azimuth.—*a.* At all points along the vertical line through the point selected as the origin of the grid system (the central meridian) the grid north and south line is coincident with the true north and south line. It has been shown in a preceding paragraph that the meridians on each side of the central meridian converge toward it. Since in any zone all grid lines are parallel to the central meridian, there will result a divergence of the grid north and south lines from the geographic north and south meridians at all points except along the central meridian. This divergence results in a difference between the grid azimuth and true azimuth of any line except a north and south line on the central meridian. Referring to figure 4, it is readily apparent that at all points east of the central meridian, grid north is east of true north and the grid azimuth is *less* than the true azimuth, while at all points west of the central meridian, grid north is west of true north and the grid azimuth is *greater* than the true azimuth. In figure 4, the solid lines represent true north and south lines, and the broken lines represent grid north and south lines. The difference between the true azimuth and the grid azimuth of the line *AB* is the angle *PAG*, which represents the convergence of the meridians between the point *A* and the origin of the grid system.

b. The general formula for the difference between true azimuth and grid azimuth is: Divergence (in angular value) equals difference in longitude between the central meridian of the zone and the point for which the divergence is desired (in angular value) times sine of the latitude of this point. The value of the divergence obtained

by the use of this formula will be expressed in degrees, minutes or seconds, according to which unit is used to express the difference in longitude. It should be remembered that this formula is accurate to within a few seconds only (depending on the difference in longitude between the central meridian and the observer's station), and that if a more precise value is desired, table L, TM 5–236 (corrections for the reduction of geographic azimuths to grid azimuths), should be used. However, since for most practical artillery purposes it is sufficiently accurate to determine azimuths to the nearest half minute, the formula is sufficiently accurate and saves making a difficult interpolation in table L, TM 5–236.

c. It should be noted that the back grid azimuth of a line differs from its forward grid azimuth by exactly 180°. (See pars. 76 and 118*d*, TM 5–235.)

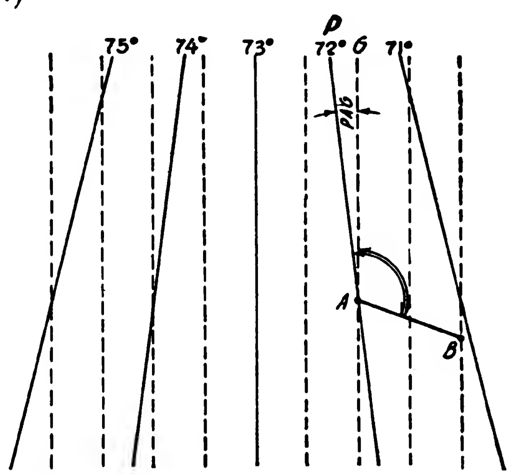

FIGURE 4.—Geographic and grid azimuths.

27. Computation of grid azimuth and distance.—*a.* The direction or azimuth of a line is measured in a clockwise direction from the north or from the south point. Orientation of artillery installations in harbor defenses is computed to read azimuths from south, as zero. Mobile artillery units designate azimuths as measured from zero north. Azimuths may be expressed in degrees from 0 to 360, or in mils from 0 to 6400. In this text, the azimuth of a line, unless otherwise stated, is the horizontal angle measured in a clockwise direction from grid north. In figure 5, the angle α represents the grid azimuth of the line AB.

b. The bearing of a line is the horizontal angle which it makes with a north and south line; it is usually expressed in a value less than 90° and, therefore, it is sometimes measured from the north and sometimes from the south, clockwise or counterclockwise. In figure

5 the angle β represents the bearing of the line AB. The bearing of a line is always the angle whose tangent is $\frac{\Delta x}{\Delta y}$.

NOTE: Δ is used as the symbol for difference.

It is always good practice, in determining the azimuth of a line whose coordinates are given, to draw a rough diagram similar to the one in figure 5 and note by inspection what quadrant the line is in and its approximate azimuth. In converting bearings to azimuths it should be remembered that bearings in the first and fourth quadrants are measured from grid north and bearings in the second and third quadrants are measured from grid south.

c. The azimuth and distance computed from the coordinates on the approved United States military grid system may not be exact, due to the fact that Δy contains the error of the polyconic projection

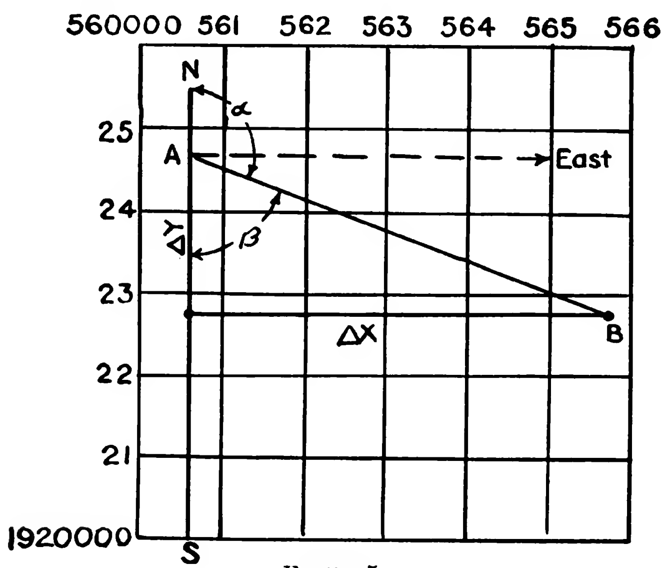

FIGURE 5.

commonly known as the magnification of scale error. When a more accurate value is required, the Δy may be corrected by the use of table XLIX, TM 5-236. The correction is based on the fact that the grid distance is always greater than the ground distance. In other words, when it is desired to convert distances computed from military grid coordinates into true distances on the ground, Δy is corrected for magnification of scale by *subtracting* the value given in table XLIX, TM 5-236. If, on the other hand, distances are actually measured on the ground and it is desired to determine the coordinates of a point, Δy, as actually measured, is corrected for magnification of scale by *adding* the value given in table XLIX, TM 5-236. In cor-

recting Δy for points in the 1° overlap between zones, care must be taken to obtain the correction for the proper zone for the map which is being used.

d. Example.—Given the grid coordinates of two points, *A* and *B*, as shown below, compute the azimuth and distance from *A* to *B*. (Latitude, 39°50′ N; longitude, 77°30′ W; zone A.)

	X	*Y*
A	560, 593. 1	1, 924, 685. 3
B	565, 784. 7	1, 922, 807. 0
	$\Delta x=$ 5, 191. 6	$\Delta y=$ 1, 873. 3
Correction (table L, TM 5-236)		−3. 4
		$\Delta y=$ 1, 874. 9

$$\text{tan bearing } (\beta)=\frac{\Delta x}{\Delta y}$$

Log 5, 191. 6 (Δx)	=3. 715301
Log 1, 874. 9 (Δy)	=3. 272978 (subtract)
Log tan bearing (β)	=0. 442323
β	=70°08′36″ (E of S)
Subtract from	180°00′00″
Azimuth *AB*	=109°51′24″

$$AB=\Delta x/\sin\beta$$

Log 5, 191. 6	=3. 715301
Log sin 70°08′36″	=9. 973380 (subtract)
Log *AB*	=3. 741921
AB	=5, 519. 8 yards.

NOTE: *AB* can also be obtained by the use of Δy in the equation $AB=\Delta y/\cos\beta$.

28. Magnification of scale correction.—*a.* The use of the correction for magnification of scale as shown in Table XLIX, TM 5-236, has a broader application than in the simple determination of correct grid azimuth, as illustrated in preceding paragraphs. As noted above, the error in the north-south direction is appreciable as soon as one works away from the central meridian of the zone. This error may be calculated in percent (or yards error per 100 yards) by the formula given in paragraph 19, or it can be found by double interpolation from table XLIX, TM 5-236, in terms of yards error per 1,000 yards. The distortion appears in the north-south vector of any line when we are working with military grid coordinates. The distortion decreases with increasing latitude, but increases with longitudinal difference between the point under discussion and the central meridian of the zone. It actually ranges from zero at all points on the central

meridian to 2.754 yards per 1,000 yards in the north-south direction at 24° north latitude, and at the edge of the zone, or 4.5° from the central meridian. One thousand yards on the ground in a north-south direction when placed on the map (or when obtaining the military grid coordinates of the point) must be stretched by this distortion or by the "magnification of scale correction", to make it fit the map. Likewise, in taking coordinates from the map, to obtain ground distances, or azimuth, the dY, or the north-south vector of the line must be shrunk by the same correction. For example, 1,000 yards in a north-south direction on the ground at latitude 24° north, and longitude 76°30′ west, would actually have to be stretched until it was $1{,}000+2.754=1{,}002.754$ on the map. Similarly, if we took the distance from the map in order to obtain the ground distance, the map distance of 1,002.754 yards would have to be shrunk by 2.754 yards, in order to obtain the proper ground distance of 1,000 yards.

b. This correction may seem small, but it is of importance in the orientation of a seacoast battery, and its neglect will cause errors of considerable magnitude to appear in the final results. It is recommended that the magnification of scale correction be habitually used, until experience shows that for particular localities, close to the central meridian, it may be safely ignored without appreciable error appearing in the orientation work.

c. For further discussion of magnification of scale corrections, see paragraphs 85 and 118*c*, TM 5-235.

Section VI

TO FIND GRID COORDINATES OF A POINT BY SURVEY

29. General.—*a.* In case it is desired to determine the grid coordinates of a point from which no known points are visible, a traverse is employed. Since a gun position is ordinarily chosen so as to take advantage of defilade, thus decreasing the visibility from the position, it is probable that frequently the coordinates of such positions must be determined by means of a traverse run from some point whose coordinates are known. As stated above, the transit may be used and the coordinates computed from the field notes, or the plane table

may be used and the coordinates scaled from the plane table sheet. Both methods are described in TM 5-235.

b. A traverse may be defined as the measurement of the lengths and azimuths of certain lines on the ground, starting at some known point, for the purpose of determining the coordinates of another point or points. From this it is seen that the data which must be known before going into the field are: first, the grid coordinates of the starting point, and second, the azimuth from the starting point to some point which is visible from the starting point (or, in the case of a plane table traverse, a method of orienting the plane table at each set-up).

30. To find grid coordinates of a point.—*a*. There are three methods of determining the grid coordinates of a point by means of ordinary surveying instruments; namely, resection, traverse, and intersection. In all three of these methods, either the transit may be used and the coordinates computed from the field notes, or the plane table may be used and the coordinates scaled from the plane table sheet. For the purpose of obtaining orientation data for coast artillery organizations, the transit method is considered as standard. The plane table method, because of its comparative inaccuracy, will be used only when speed is of greater importance than accuracy.

b. All of the methods of determining coordinates mentioned above involve the solution of certain plane triangles, knowing certain elements of the triangles. The known elements may be any combination of angles and sides of the triangles for which a trigonometrical or graphical solution is possible.

c. Detailed instructions for the conduct of a transit traverse are contained in paragraph 75, TM 5-235, and instructions for the adjustment of a closed traverse appear in section XIII, TM 5-235.

d. A sample calculation of a transit traverse run from bench mark No. 7 to a gun position, a problem applicable to the Coast Artillery Corps, is given below:

CALCULATION OF TRANSIT TRAVERSE

Name ....
Group and section ....
Time required ....

Longitude: 75°48′ W.
Latitude: 37°02′ N.
Δy correction per 1,000 yards .766.

Place: Fort Monroe, Va.
Traverse: BM 7 to Gun No. 1.
Date: Oct. 30, 1940.

Station	Azimuth	Bearing	Distance (feet)	Calculation Δx	Calculation Δy	Δx +E	Δx −W	Δy +N	Δy −S	Coordinates X	Coordinates Y
	° ′	° ′								Bench M No. 7	
BM 7 to 1	115 24	S64 36E.	870	log sin β=9.955849 log dist.=2.939519 log Δx=2.895368 Δx=785.9	log cos β=9.632392 log dist.=2.939519 log Δy=2.571911 Δy=−373.2	785.9			373.2	675,578.0 +1,978.4 677,556.4	1,580,779.5 −1,302.3 1,579,477.2
1 to 2	73 40	N73 40E.	1,200	log sin β=9.982109 log dist.=3.079181 log Δx=3.061290 Δx=+1,151.6	log cos β=9.449054 log dist.=3.079181 log Δy=2.528235 Δy=+337.5	1,151.6		337.5		Gun No. 1	
2 to 3	119 24	S60 36E.	1,900	log sin β=9.940125 log dist.=3.278754 log Δx=3.218879 Δx=+1,655.3	log cos β=9.690996 log dist.=3.278754 log Δy=2.969750 Δy=−932.7	1,655.3			932.7		
3 to 4	136 45	S43 15E.	2,250	log sin β=9.835807 log dist.=3.352183 log Δx=3.187990 Δx=+1,541.7	log cos β=9.862353 log dist.=3.352183 log Δy=3.214536 Δy=−1,638.8	1,541.7			1,638.8		
4 to 5	148 21	S31 39E.	1,500	log sin β=9.719935 log dist.=3.176091 log Δx=2.896026 Δx=+787.1	log cos β=9.930067 log dist.=3.176091 log Δy=3.106158 Δy=−1,276.9	787.1			1,276.9		
5 to Gun	143 21	S36 39E	23	log sin β=9.775920 log dist.=1.361728 log Δx=1.137648 Δx=+13.7	log cos β=9.904335 log dist.=1.361728 log Δy=1.266063 Δy=−18.5	13.7			18.5	3,902.61′=1,300.9 yds. Magnification scale= 1.4 yds. ΔY= 1,302.3 yds.	
				log sin β= .... log dist.= .... log Δx= .... Δx=	log cos β= .... log dist.= .... log Δy= .... Δy=						
					5,935.3′ =	5,935.3 1,978.4	.... yards.	337.5	4,240.1 337.5 3,902.6		

31. Computation of transit traverse.—*a.* In the computation of a traverse, it is sufficiently accurate to use the adjusted value of the azimuths to the nearest minute, and to use five-place logarithms. Any errors thus introduced will be compensating and the computation is facilitated. The complete computation of the field record and the form used in accomplishing the computation are shown below:

Latitude, 37°02′ North.
Longitude, 75°48′ West.
Magnification of scale correction for Δy (see table XLIX, TM 5-236) =0.766 yards per 1000.

b. In the computation of the Δx and Δy increments, the measured station-to-station distance is the hypotenuse of a right triangle of which the legs are the desired Δx and Δy values. The angle used in solving each right triangle to obtain the Δx and Δy increments for each traverse line is the bearing angle of that line, measured from one station to the next succeeding station. For example, in the solution of the first triangle, the azimuth of the line B. M. No. 7 to station 1 is 115°24′. The bearing of this line is 180°–115°24′, or *S* 64°36′ *E*, which is the angle to be used in the solution of the triangle. By always using the bearing angle, Δx for any given traverse line is equal to the length of that line times the *sine* of the bearing angle, and Δy for that line is equal to the length of the line times the *cosine* of the bearing angle.

c. In determining the proper signs for the Δx and Δy increments, it must be remembered that distances measured to the north of an east-and-west line through any given station are positive Δy increments, and distances measured to the east of a north-and-south line through the point are positive Δx increments. Whether these increments are positive or negative may be determined by inspection of the directions given in the column "Bearing." For example, in the computation of the Δx and Δy of the distance from station 2 to station 3, the bearing angle was *S* 60°36′ *E*. The "*S*" indicates that the Δy will be negative, and the "*E*" that the Δx will be positive.

d. As each Δx or Δy increment is computed, its value is entered in the proper column (east, west, north, or south). The algebraic sums of the Δx's and of the Δy's are then computed, and, after correcting the Δy for magnification of scale, are added to the coordinates of the starting point to obtain the coordinates of the desired point.

e. The use of *natural* trigonometric functions and a calculating machine materially simplifies and expedites the computation of a transit traverse and at the same time offers less liability to mistakes in computation. In most cases for mobile artillery orientation, the precision obtainable from a 20″ slide rule permits its use in lieu of a calculating machine.

32. Location of a point by intersection.—*a*. Intersection is a simple form of triangulation. It consists of sighting an unknown, unoccupied point from two known points and then determining the position of the point of intersection of these two lines of sight. This may be done trigonometrically with the transit, or graphically with the plane table. The problem is to solve an oblique plane triangle having given two angles and the included side.

b. Intersection is commonly employed in running a traverse, either by transit or plane table, to locate an auxiliary point off the traverse without the necessity of measuring the distance to it. It is frequently an advantageous way to locate an inaccessible point. The accuracy with which a point may be located by intersection depends upon the precision of measurement of the base line, the effective length of the base line, and the precision of measurement of the two angles. For artillery purposes the base line should be of such length that the angle subtended by it at the unknown point is not less than 10°. When locating a point off a traverse, one of the traverse lines is frequently used as the base line.

c. One measurement of an angle (that is, obtaining the angle by taking the difference between the readings of the same vernier when the transit is pointed first on one point and then on the other) does not give an exact value of the angle, as the value so obtained can never be more accurate than the least reading of the vernier. In measuring an angle, added accuracy is obtained by measuring an angle by repetition. For artillery computations, angles are usually measured by six repetitions; that is, three times with the telescope direct, and three times with the telescope reversed. The telescope should always be turned (rotated) in a clockwise direction.

33. Mathematical solution of intersection problem.—*a*. The problem of determining the coordinates of a point by intersection consists of solving trigonometrically an oblique triangle knowing two angles and the included side. In figure 6 the side *AP* has been measured or can be computed if the coordinates of *A* and *B* are known. The transit is set up at *A* and the angle *BAP* is measured by repe-

tition. The transit is then set up at *B* and the angle *ABP* is similarly measured. The triangle *ABP* is then solved by the law of sines and the coordinates of *P* are computed from the point *A* or *B*, or from both *A* and *B* if a check on the computation is desired.

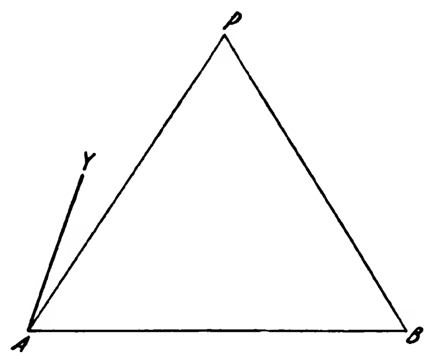

FIGURE 6.—Determination of coordinates by intersection.

b. The following example illustrates the method of computation: Given the grid coordinates of two points—

$$A\ X=1{,}437{,}896.0 \qquad Y=1{,}585{,}450.0$$
$$B\ X=1{,}438{,}669.0 \qquad Y=1{,}585{,}666.0$$
Latitude 37°00′ N.; longitude 76°30′W.

A transit was set up at *A* and *B* and the following angles were measured to point *P* whose position was desired:

Angle $BAP=66°15'30''$
Angle $ABP=67°28'00''$

Required the coordinates of *P*.

First step—solution by way of side *AP*.

$$A\ X=1{,}437{,}896.0 \qquad Y=1{,}585{,}450.0$$
$$B\ X=\underline{1{,}438{,}669.0} \qquad Y=\underline{1{,}585{,}666.0}$$
$$\Delta x=773.0 \qquad \Delta y=216.0 \text{ (uncorrected)}$$

Correction for magnification of scale for point at $\phi=37°00'$ north and $\lambda=76°30'$ west is from table XLIX, TM 5-236, 1.190 yards per thousand.

$$1.190\times .216=0.26 \text{ or } 0.3 \text{ yards.}$$

Therefore Δy corrected $= 216.0-0.3=215.7$ yards.

Tangent bearing of $AB=\Delta x/\Delta y=773.0/215.7$

(Seven-place logarithms are used if angles are measured by repetition. In this example seven-place logarithms are used).

Log 773.0=2.8881795
Log 215.7=2.3338501

Log tangent bearing =0.5543294
Bearing AB=74°24′31″ east of north
Grid azimuth of AB=74°24′31″
$AB=\Delta x/\sin$ bearing=
Log Δx=12.8881795–10
Log sin 74°24′31″= 9.9837178–10

Log AB= 2.9044617 (AB=802.53)

Second stop—Determine azimuth and length of line AP.

By law of sines $AP/\sin B = AB/\sin P$ or $AP = AB \times \sin B/\sin P$

Solving for AP: Log AB =2.9044617
log sin ABP=9.9655106–10
colog sin APB=0.1410626

log AP=3.0110349
AzAB=74°24′31″
Angle BAP=66°15′30″

Az AP= 8°09′01″ (subtracting)
Δx of $AP=AP$ sin bearing AP
Log AP=3.0110349
log sin 8°9′1″=9.1515841–10

Log Δx=2.1626190
Δx=145.4 yards.

Δy of $AP=AP$ cos bearing AP
Log AP=3.0110349
log cos 8°9′1″=9.9955912–10

Log Δy=3.0066261
Δy=1015.4 yards (uncorrected)

Magnification of scale correction=1.190 × 1.015=1.2.
Δy corrected=1015.4+1.2=1,016.6 yards

Coordinates: A	X=1,437,896.0	Y=1,585,450.0
	ΔX of AP +145.4	Δy of AP +1016.6
	X=1,438,041.4	Y=1,586,466.6

SECTION VII

DETERMINATION OF ELEVATION DIFFERENCES

34. General.—*a.* The two principal methods for the determination of the difference of elevation between two stations, or the establishment of the elevation of a new station with reference to a known datum plane are:

(1) Differential leveling, or spirit leveling, by which difference in elevations is obtained by the use of an engineers' level and graduated rod. This method is explained in paragraph 54, TM 5-235.

(2) Trigonometric leveling, by which the difference of elevation between two stations is determined mathematically from the relationship between the distance and the vertical angle between the two stations. This method is explained in paragraphs 50 and 110 and subparagraph 117*h*, TM 5-235.

b. Instructions relative to the use of leveling instruments and auxiliary equipment appear in paragraph 51, TM 5-235.

c. An example of profile leveling will be found in paragraph 55, TM 5-235.

d. General information relative to curvature, refraction and *K* correction angles is given in paragraph 110, TM 5-235.

SECTION VIII

AZIMUTH DETERMINATION

35. General.—*a.* One of the primary duties of a reconnaissance officer is to furnish the battery commander with orienting lines for his guns and observation stations. If two intervisible points whose coordinates are known are located in the vicinity, or if a line of known azimuth is available, the problem is simple. But if these data are not available it becomes necessary for the reconnaissance officer to deter-

mine an azimuth by making an astronomical observation or, for a hasty set-up, to use an orienting line established by compass for each battery position. No appreciable error in firing data will result provided that all elements are based on the same orientation. The determination of azimuth is an important and exacting phase of orientation. It is essential, therefore, that the reconnaissance officer be thoroughly familiar with the methods of determining azimuth outlined in this section.

b. Astronomical observations are taken either on the sun or on a star, preferably Polaris. The problem is primarily one of locating in direction the sun or star in the sky with respect to a terrestrial datum point. Since the earth is rotating, the positions of celestial bodies except circumpolar stars in the sky always appear to be moving constantly from east to west. It is obvious, therefore, that the position of any celestial body with respect to the observer's position on the earth is a function, not only of its actual position in space, but also of the amount of rotation of the earth, or in other words, the time of day. This chapter outlines briefly the elements of practical astronomy and their application to the problem of coordinating time of observation with the position of a particular celestial body.

c. After the observations have been made, it is necessary to solve the astronomic triangle to determine the bearing of the celestial body. There are several methods of solving this triangle but the *hour angle method* best fulfills the needs of a coast artilleryman. Knowing the hour angle, the procedure for the solution of the remainder of the celestial triangle is by one of the following methods:

(1) By the formula, using the tangent of one-half angles. This gives great accuracy when using seven-place log tables and is applicable for practically any position of a heavenly body.

(2) By the Ageton method, which uses formulas based on secants and cosecants. The Ageton tables are logarithm tables multiplied by 100,000 to eliminate the decimal point. These tables require very little interpolation and are within the accuracy of reading of the transit. The Ageton method of computation of the angle is used in surface and air navigation.

36. Meridians.—*a*. As stated previously, the azimuth of a line is considered in this manual to be the direction of the line, given as an angle, measured in a clockwise direction from grid south or grid north. In this chapter azimuth is considered as measured from *true* meridian, since azimuths determined by astronomical observations are true azimuths.

b. The basis of azimuth determination is the location of the true meridian of the observer. True north for any observer is represented on the earth by the arc of a great circle, between the observer and the north pole, created by the cutting of the surface of the earth by a plane through the observer and the north and south poles. This great circle is known as the observer's true meridian. True azimuths are measured clockwise from the true meridian. Similarly, grid and magnetic azimuths are measured from the grid and magnetic meridians. The meridians defined in this paragraph are the meridians of the earth's surface; that is, terrestrial longitude lines. It will be found later that in dealing with distant heavenly bodies our conception of a meridian must be enlarged so that we may fit it into celestial space.

37. Determination of meridianal direction.—*a.* True north is determined by astronomical observations taken either on the sun or on a star. In general, this consists of measuring the angle between the position of the sun or star and a datum point and recording that angle together with the exact time of day. Then, by referring to tables for that body in the Nautical Almanac, its actual azimuth can be computed for the exact time and date of the observations. Having found this true azimuth of the sun or star and the measured angle between it and the datum point, the azimuth of the datum point is established.

b. Magnetic north is the direction indicated by the magnetic compass. Magnetic declination from true north may be determined to an accuracy of about 10′ by referring to an up-to-date isogonic chart of the United States.

c. Grid north may be determined by applying a correction to true north for the divergence of the observer's meridian from the central meridian. The method of doing this is covered in a preceding paragraph. If the grid coordinates of two intervisible points are known, grid north may be determined by simply solving for the azimuth of the line joining the two points. The amount of the grid convergence may be obtained for your latitude from the appropriate table in United States Coast and Geodetic Survey Special Publication No. 59.

38. Celestial coordinates.—*a.* Just as gun batteries and datum points have coordinates, so have the stars. Whereas datum points have terrestrial latitude measured from the earth's equator and terrestrial longitude measured from the meridian of Greenwich, stars have celestial latitude and longitude.

(1) *Declination.*—Celestial latitude is called declination and is measured in degrees, minutes, and seconds of arc north or south of the celestial equator.

(2) *Right ascension.*—Celestial longitude is called right ascension and is measured in hours, minutes, and seconds of time in a clockwise direction from the vernal equinox (*VE*).

b. The location of a celestial body may be defined by one of several systems of coordinates used in connection with the celestial sphere. There are but three commonly used systems which need consideration in connection with azimuth problems (see par. 164*l*, TM 5-235).

39. General definitions.—Before proceeding with the determination of azimuth by astronomical observation, a very careful study should be made of section XXVIII, TM 5-235, to learn or to refresh the memory with the meaning and significance of the following terms:

a. Time.—(1) Sun or solar time, which is divided into—
Standard time.
Apparent time.
Mean time.

(2) Sidereal or star time.

(3) Determination of time.
Greenwich civil time.
Greenwich apparent time.
Greenwich sidereal time.

(4) Conversion of time.

b. Vernal equinox.—The hour angle of the VE is called sidereal time.

c. Right ascension.—The right ascension of any celestial body when at upper culmination is the sidereal time at that instant.

d. Transit of Polaris.
Upper and lower culmination.
East and west elongation.

e. Hour angle.—The hour angle of a star depends on the sidereal time and the right ascension of the star.
Greenwich hour angle.
Local hour angle.

f. Declination.

g. The celestial sphere and the apparent motions of the earth and all celestial bodies, and a knowledge of the fundamental astronomic positions, distances and angles which are contained in the celestial sphere (see fig. 132 and par. 164, TM 5-235).

h. A thorough comprehension of the astronomic triangle is necessary before the solution of azimuth problems can be understood (see fig. 136 and par. 167, TM 5-235).

i. Attention is invited to paragraph 168, TM 5-235, for a comparison of the advantages of the various methods of astronomical obser-

vations and the degree of accuracy which may be expected from each type of computation.

j. For procedure to be followed for making an observation on the sun, see paragraph 169, TM 5–235.

k. For procedure to be followed to make an observation on a star, see paragraph 170, TM 5–235.

40. Computation of Greenwich hour angle.—*a.* An hour angle is the angle measured in a counterclockwise direction (looking from the earth towards the north celestial pole) between the upper meridian and the celestial body. There are several methods of computing hour angles which involve the difficult computation of local apparent time and local sidereal time. This conversion of local civil time into sidereal time will not ordinarily be required in the determination of azimuth by the coast artilleryman and, in order to avoid confusion, will not be dealt with in this manual. The method of making these conversions, if desired, may be found in TM 5–235.

b. The American Nautical Almanac contains tables in which appears the Greenwich hour angle of the sun for each two hours for every day of the year. Corrections for the hour, minute and second of observation may also be read from the tables in the Almanac. This gives a rapid determination of the hour angle of the sun at Greenwich without the confusion of sidereal time or an "equation of time." Similar tables give the hour angles at Greenwich for all the most commonly used celestial bodies. The stellar tables give the *GHA* for 0^h (midnight) for *GCT* for each day in the year. This value must be corrected for the time of observation.

c. To find the Greenwich hour angle:

	H	*M*	*S*
GCT of observation (sun), October 6, 1941	13	28	16
GHA of sun (table I, app. I) at 12^h		2°56.9′	
Correction for one hour and 28 minutes		22°00.0′	
Correction for 16 seconds		4.0′	
GHA of sun at time of observation		25°00.9′	

d. Considering the time of observation at $7^h43^m09^s$ PM, October 6, 1941, taken at Fort Monroe, Virginia, (longitude 76°18′ W.) (see fig. 7). To find the *GHA* of Polaris:

	H	*M*	*S*
Time of observation, October 6, 1941	7	43	09
Watch correction 6 seconds fast	−		06

EST of observation, PM	7	43	03
Correction to 0-24 hour clock	19	43	03
Correction for 75° *W*. longitude	+ 5	00	00
GCT of observation, October 6th	24	43	03
GCT of observation, October 7th	0	43	03
GHA of Polaris (table II, app. I)		348°56.3′	
Correction for 0^h43^m		10°46.8′	
Correction for 3 seconds (table III, app. I)		0.8′	
GHA at time of observation		359°43.9′	

41. Determination of local hour angle (*LHA*).—*a*. The local hour angle (*LHA*) of a celestial body is the algebraic sum of the Greenwich hour angle of that body and the longitude of the point from which the observation was taken. Hour angles are measured counterclockwise from the Greenwich upper meridian (see fig. 7). Therefore, west longitude becomes negative and east longitude is positive for the purpose of determining local hour angles (*LHA*) from the Greenwich hour angle (*GHA*).

b. For example: Continuing the problem given above—

(1)

GHA of Polaris at time of observation	359°43.9′
Point of observation, Fort Monroe, Virginia	−76°18.4′
LHA of Polaris at time of observation	283°25.5′

(2) Likewise for the observation taken on the *sun* from Fort Monroe on October 6, 1941, the recapitulation is as follows:

	H	*M*	*S*
EST of observation, October 6, 1941	8	27	38
Watch error 38 seconds slow	+		38
Corrected *EST*	8	28	16
Correction for 75th meridian	+ 5	00	00
GCT of observation	13	28	16
GHA of sun, October 6, 1941 (table I, app. I) at 12^h		2°56.9′	
Correction for 1 hour, 28 minutes		22°00.0′	
Correction for 16 seconds		4.0′	
GHA of sun at time of observation		25°00.9′	
Longitude Fort Monroe (subtract)		−76°18.4′	
Local hour angle (*LHA*) (sun)		308°42.5′	

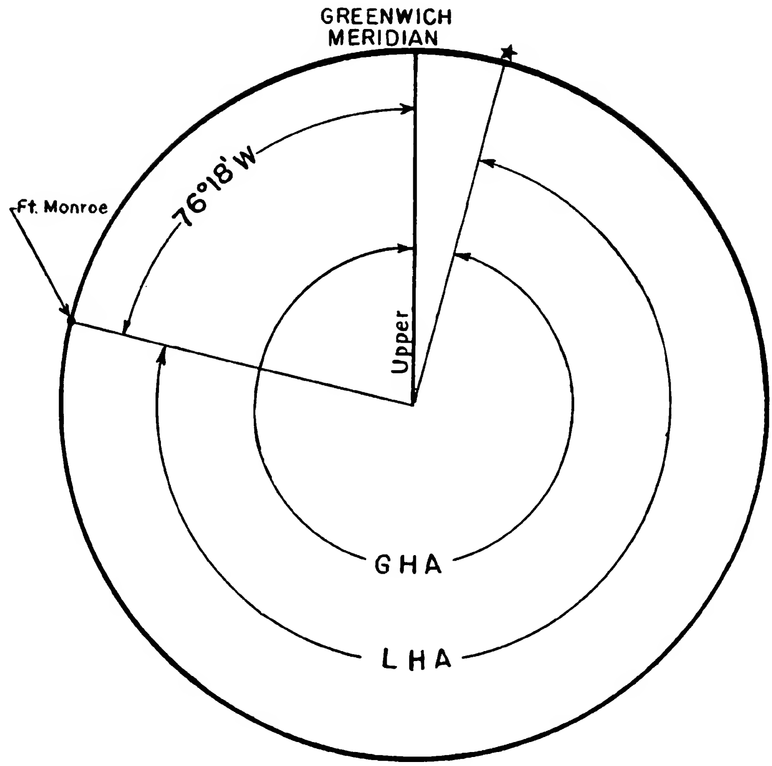

FIGURE 7.—Hour angle of Polaris.

42. Methods of azimuth determination.—TM 5-235 contains instructions, formulas, and examples for determining azimuths from observations on the sun or on a star by the two following methods:

Altitude method.

Hour angle method.

a. Altitude method.—(1) Some of the disadvantages of the altitude method are that—

(*a*) An error of one minute in either latitude, declination, or altitude may cause a corresponding error of over half a minute in azimuth.

(*b*) Simultaneous readings must be made of the horizontal and vertical angles.

(*c*) Because of the apparent rapid movement of the sun, much difficulty is experienced in keeping the sun's image in the proper quadrant and tangent to the vertical and horizontal cross wires.

(*d*) Corrections must be applied to the vertical angular readings for parallax and refraction of light by values obtained from tables in TM 5-236.

(2) The advantages of the altitude method are that the office computation is relatively simple in comparison with other methods, and

that the watch time of observation is not a critical item and need only be known to the nearest two or three minutes. A watch error of five minutes will change the azimuth by only ten seconds. However, a watch's error to the nearest second is easily obtained from radio time signals so that the advantage of approximate time is no longer of sufficient importance to outweight the disadvantages given in (1) above.

b. The determination of azimuth by the hour angle method fulfills the requirements of the Coast Artillery Corps, and a simpler method than the one explained in paragraph 173, TM 5–235, appears in paragraph 43.

(1) The use of the American Nautical Almanac (instead of the Ephemeris) for the current year, greatly simplifies the computation of the local ho angle, because the Greenwich hour angle (*GHA*) of the sun and ny of the stars is published in the Almanac for every day of the ye

(2) To obt n the *LHA*, simply subtract the longitude of the place of obse tion from the *GHA* of the heavenly body corrected for the time c observation. Examples of this method of azimuth determination appear in paragraphs 43 and 44.

c. The use of the Ageton method has been found to be very expeditious for azimuth determination, and examples of this method are included in this manual.

43. Computation of azimuth by tangent formula (hour angle method).—*a.* To determine the true azimuth of a position, there are three distinct steps to be made in the computation; they are:

(1) To find the local hour angle (*LHA*) and declination of the heavenly body as previously described.

(2) To find the bearing (β) of the celestial body by the solution of the astronomic triangle using one of the formulas given above.

(3) To correct this bearing (β) to true azimuth, by combining the bearing with the measured angle of the point sighted, and the grid divergence of the locality in which the observation was taken.

(4) These steps in computation are shown on the model forms and should be followed in that order.

b. Rules for computations.—(1) If the algebraic sign of the quantity ($\phi-d$) is positive, the bearing will be the numerical sum of the angles ½ ($\beta+q$) and ½ ($\beta-q$).

(2) If the algebraic sign of the quantity ($\phi-d$) is negative, the bearing will be the numerical difference of the two angles.

c. Examples of computation.

Solar observation (hour angle method)

(Azimuth determination)

Station: 4.
S.: Sun.
Mark: Sta. A.

Longitude: 76°18.4′.
Latitude (ϕ): 37°00.0′.
Watch: Slow 38 sec.

Date: 6 Oct. 1941.
Place: Ft. Monroe, Va.
Name:

Hour angles	1st set °	′	″	2d set °	′	″	3d set °	′	″
Time of observation (0–24 hrs.)	8	27	38	8	42	22	8	57	31
Watch correction			+38			+38			+38
Corrected time of observation	8	28	16	8	43	00	8	58	09
Time difference Greenwich	5			5			5		
Greenwich civil time of observation	13	23	16	13	43	00	13	58	09

	1st set °	′	2d set °	′	3d set °	′
Greenwich H. A. (almanac)	2	56.9	2	56.9	2	56.9
Correction (hrs. & mins.)	22	00.0	25	45.0	29	30.0
Correction (seconds)		4.0		0.0		2.3
GHA (time of observation)	25	00.9	28	41.9	32	29.2
Longitude: W(−) E(+)	−76	18.4	−76	18.4	−76	18.4
LHA (−) or (+)	−51	17.5	−47	36.5	−43	49.2

To find LHA, add GHA and longitude algebraically, subtracting 360° if necessary.
If LHA is greater than 180°, subtract from 360°.

Bearings (β)	° ′ ″		° ′ ″	$\tan \frac{1}{2}(\beta+q) = \frac{\cos \frac{1}{2}(\phi-d) \cot \frac{1}{2} \text{LHA}}{\sin \frac{1}{2}(\phi+d)}$		$\tan \frac{1}{2}(\beta-q) = \frac{\sin \frac{1}{2}(\phi-d) \cot \frac{1}{2} \text{LHA}}{\cos \frac{1}{2}(\phi+d)}$	
LHA	51 17 30	½ LHA	25 38 45	cot	0.3186650	cot	0.3186650
Lat. (ϕ)	37 00 00	½ ($\phi-$d)	21 02 50	cos	9.9700142	sin	9.5552605
Decl (d)	−5 05 40	Numerator		log	0.2886792	log	9.8739255
($\phi-$d)	42 05 40	½ ($\phi+$d)	15 57 10	sin	9.4390879	cos	9.9829441
($\phi+$d)	31 54 20			tan	0.8495913	tan	9.8909814
$\beta_1 = \frac{1}{2}(\beta+q) + \frac{1}{2}(\beta-q) =$			119 50 08	½ ($\beta+$q)	81 57 09	½ ($\beta-$q)	37 52 59
LHA	47 36 30	½ LHA	23 48 15	cot	0.3554241	cot	0.3554241
Lat (ϕ)	37 00 00	½ ($\phi-$d)	21 02 58	cos	9.9700077	sin	9.5553042
Decl (d)	−5 05 55	Numerator		log	0.3254318	log	9.9107283
($\phi-$d)	42 05 55	½ ($\phi+$d)	15 57 03	sin	9.4390363	cos	9.9829483
($\phi+$d)	31 54 05			tan	0.8863955	tan	9.9277800
$\beta_2 = \frac{1}{2}(\beta+q) + \frac{1}{2}(\beta-q) =$			122 51 24	½ ($\beta+$q)	82 35 56	½ ($\beta-$q)	40 15 28
LHA	43 49 12	½ LHA	21 54 36	cot	0.3955577	cot	0.3955777
Lat (ϕ)	37 00 00	½ ($\phi-$d)	21 03 05	cos	9.9700020	sin	9.5553425
Decl (d)	−5 06 10	Numerator		log	0.3655597	log	9.9509202
($\phi-$d)	42 06 10	½ ($\phi+$d)	15 56 55	sin	9.4389773	cos	9.9829531
($\phi+$d)	31 53 50			tan	0.9265824	tan	9.9679671
$\beta_3 = \frac{1}{2}(\beta+q) + \frac{1}{2}(\beta-q)$			126 08 08	½ ($\beta+$q)	83 14 48	½ ($\beta-$q)	42 53 20

Grid azimuth: Bearing (β) is West if LHA is (+), East if (−).

	° ′ ″	° ′ ″	° ′ ″
Bearing (β) East or West	119 50 08	122 47 30	126 08 03
True azimuth to S	119 50 08	122 51 24	126 08 08
Average angle to mark	93 42 00	96 43 30	100 00 00
True azimuth to mark	26 08 08	26 07 54	26 08 08
Mean true azimuth to mark			26 08 03
Grid divergence			+1 59 10
Grid azimuth to mark			28 07 13

Polaris observation (hour angle method)

(Azimuth determination)

Station: A.	Longitude: 76°18.4.′	Date: 6 Oct. 1941.
S: Polaris.	Latitude (ϕ): 37°00.0.′	Place: Fort Monroe, Va.
Mark: Bug Light.	Watch: Fast 6 sec.	Name:

Hour angles	1st set			2d set			3d set		
	°	′	″	°	′	″	°	′	″
Time of observation (0–24 hrs.)	19	43	09	19	46	59	19	49	16
Watch correction			−6			−6			−6
Corrected time of observation	19	43	03	19	46	53	19	49	10
Time difference Greenwich +	5			5			5		
Greenwich civil time of observation (Oct. 7)	0	43	03	0	46	53	0	49	10

	1st set		2d set		3d set	
	°	′	°	′	°	′
Greenwich H. A. (almanac)	348	56.3	348	56.3	348	56.3
Correction (hrs. & mins.)	10	46.8	11	31.9	12	17.0
Correction (secs.)		0.8		13.3		2.5
GHA (time of observation)	359	43.9	360	41.5	361	15.8
Longitude: W(−) E(+)	−76	18.4	−76	18.4	−76	18.4
LHA (−) or (+)	283	25.5	284	23.1	284	57.4

To find LHA, add GHA and longitude algebraically, subtracting 360° if necessary.
If LHA is greater than 180°, subtract from 360°.

Bearings (β)								$\tan \frac{1}{2}(\beta+q) = \dfrac{\cos \frac{1}{2}(\phi-d) \cot \frac{1}{2} \text{LHA}}{\sin \frac{1}{2}(\phi+d)}$		$\tan \frac{1}{2}(\beta-q) = \dfrac{\sin \frac{1}{2}(\phi-d) \cot \frac{1}{2} \text{LHA}}{\cos \frac{1}{2}(\phi+d)}$	
	°	′	″		°	′	″				
LHA	76	34	30	½ LHA	38	17	15	cot	0.1027038	cot	0.1027038
Lat. (ϕ)	37	00	00	½ (ϕ−d)	25	59	33	cos	9.9536879	sin	9.6417254
Decl. (d)	+88	59	07	Numerator				log	0.0563917	log	9.7444292
(ϕ−d)	−51	59	07	½ (ϕ+d)	62	59	33	sin	9.9498519	cos	9.6571583
(ϕ+d)	125	59	07					tan	0.1065398	tan	0.0872709
					°	′	″		° ′ ″		° ′ ″
β_1=½(β+q)+½(β−q)=					1	14	24	½(β+q)	51 57 30	½(β−q)	50 43 06
LHA	75	36	54	½ LHA	37	48	27	cot	0.1102003	cot	0.1102003
Lat. (ϕ)	37	00	00	½ (ϕ−d)	25	59	33	cos	9.9536879	sin	9.6417254
Decl. (d)	88	59	07	Numerator				log	0.0638882	log	9.7519257
(ϕ−d)	51	59	07	½ (ϕ+d)	62	59	33	sin	9.9498519	cos	9.6571583
(ϕ+d)	125	59	07					tan	0.1140363	tan	0.0947674
					°	′	″		° ′ ″		° ′ ″
β_2=½(β+q)+½(β−q)=					1	14	06	½(β+q)	52 26 14	½(β−q)	51 12 08
LHA	75	02	36	½ LHA	37	31	18	cot	0.1146795	cot	0.1146795
Lat. (ϕ)	37	00	00	½ (ϕ−d)	25	59	33	cos	9.9536879	sin	9.6417254
Decl. (d)	88	59	07	Numerator				log	0.0683674	log	9.7564049
(ϕ−d)	51	59	07	½ (ϕ+d)	62	59	33	sin	9.9498519	cos	9.6571583
(ϕ+d)	125	59	07					tan	0.1185155	tan	0.0992466
					°	′	″		° ′ ″		° ′ ″
β_3=½(β+q)+½(β−q)=					1	13	55	½ (β+q)	52 43 21	½ (β−q)	51 29 26

Grid azimuth: Bearing (β) is West if LHA is (+): East if (−).

	°	′	″	°	′	″	°	′	″
Bearing (β) East or West	1	14	24	1	14	06	1	13	55
True azimuth to S	1	14	24	1	14	06	1	13	55
Average angle to mark	77	00	30	77	00	30	77	02	30
True azimuth to mark	78	14	54	78	14	36	78	16	25
Mean true azimuth to mark							78	15	18
Grid divergence							1	59	10
Grid azimuth to mark							80	14	28

44. Computation of azimuth by Ageton method.—*a.* In this method of computation of the local hour angle and its combination with the bearing angle (β) of the celestial body is made in the same manner as indicated in paragraph 43. The solution of the astronomical triangle is based on the four formulas given in *b* below. This

solution uses a special table prepared by Lieutenant Arthur A. Ageton, United States Navy, and is simply log secants and log cosecants of all angles to five places multiplied by 100,000. This feature eliminates possible errors which might occur in misplacing the decimal point. It also reduces the total number of significant figures by using secants and cosecants as reciprocals of sines and cosines. A complete explanation of the derivation of the formula is given in HO No. 211, Hydrographic Office, United States Navy. A synopsis of the theory is as follows:

(1) In the computation of the azimuth of a celestial body by the Ageton method, the *PZS* (pole-zenith-star) triangle is solved for the bearing angle β. (See fig. 8.) The known elements of the triangle are—

(*a*) The declination (d) of the body at the time of observation (obtained from the Almanac).

(*b*) The hour angle (t) of the body at the time of observation (obtained from the Almanac).

(*c*) The latitude (ϕ) of the place of observation (obtained from the map).

(2) Referring to figure 8, it will be noted that the *PZS* triangle is divided into two right spherical triangles by a great circle through *S* perpendicular to the meridian *PZ*. The arc of this circle *SX* is called *R*. Although log secant *R* and log cosecant *R* are employed during the process of the computations, the actual value of *R* is of no interest; it is merely introduced to facilitate the solution. Another part introduced for the same reason is the arc *QX*, called *K*. The value of this part is, however, obtained and used in the solution.

b. The following equations are used:

(1) In triangle *PZS* (fig. 8):

(*a*) $\text{Csc } R = \sec d \csc t \ (LHA)$

(*b*) $\text{Csc } K = \dfrac{\csc d}{\sec R}$

(2) In triangle *ZSX*:

(*a*) $\text{Csc } h_c = \sec R \sec (K \sim \phi)$

(*b*) $\text{Csc } \beta = \dfrac{\csc R}{\sec h_c}$

c. In the right spherical triangle *PSX* the hour angle (t) and the side *PS* (the co-declination, or 90°–d) are known. *R* may be found from equation (1) (*a*). Knowing *R* and (d), *K* may be found from equation (1) (*b*). *K* is combined algebraically with the latitude (ϕ) to form the quantity ($K \sim \phi$), which is read "*K* combined with phi."

d. In the right spherical triangle ZSX, the two sides ZX $(K \sim \phi)$ and SX (R) are known. The side ZS (h_c) may be found from equation (2) (*a*).

e. The angle β is then derived from equation (*a*) (*b*). This angle is a *bearing angle*, east or west of true north. Whether the bearing is east or west depends entirely upon whether the local hour angle is greater or less than 180°. If the LHA is between 0° and 180°,

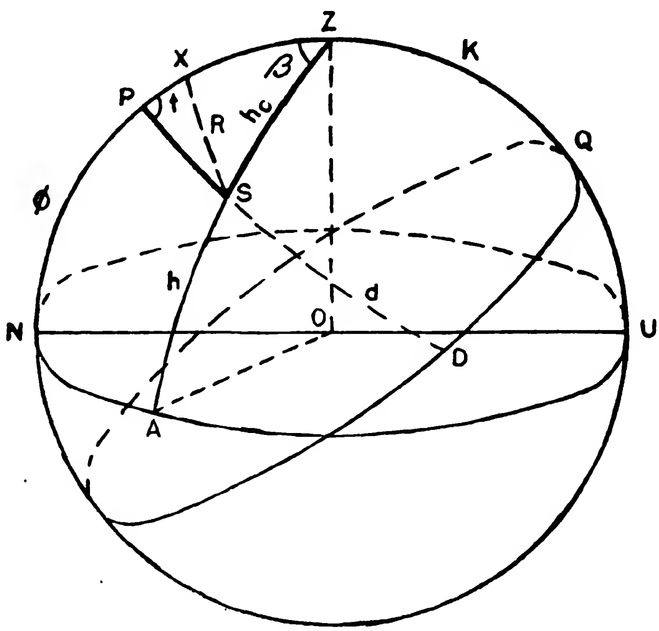

FIGURE 8.—Solution of azimuth triangle, Ageton method.

P=North celestial pole.
Z=Zenith. The bearing angle (PZS) is called β.
S=Celestial body observed.
Q=Intersection of the equator (DQ) with the meridian (NZQ).
$PN=\phi$=Latitude (altitude of the pole).
$ZQ=\phi$=Latitude (declination of the zenith).
$DS=d$=Declination of body S.
$\angle SPZ=t$=Local hour angle of S.
$AS=h$=Altitude of S.
$SX=R$=Arc of great circle through S perpendicular to PZ.
X=Intersection of R with PZ.
$QX=K$=Arc of meridian from X to the equator.
PSD=Hour circle of S.

the bearing is *west;* if the LHA is between 180° and 360°, the bearing is *east.* In the latter case the bearing is equal to the azimuth.

f. In solving each set of observations for angle β, a form or work sheet similar to that shown below and the instructions for procedure should be followed.

g. Method of solution.—(1) Obtain the Greenwich hour angle. Corrections have to be made for actual time of observation.

(2) Combine with longitude to give the local hour angle. This need only be to the nearest minute.

(3) Enter on form the declination (d) and latitude (ϕ) giving both proper sign—north (+), south (−).

(4) Enter table with local hour angle (LHA) and put down tabulated value of A function in first column.

(5) Enter table with declination (d) and put down tabulated value of B function in first column and A function in second column.

(6) Add the A and B functions in the first column. Put this value also in the fourth column.

(7) Enter table with this A function and find its equivalent B function. Put this B function down in both second and third columns.

(8) Subtract the B function from the A function in the second column. This gives the A function of K.

(9) Look up the value of K and combine with latitude (ϕ), taking difference if they are of the same sign, adding if they are of opposite sign.

(10) Enter table with ($K \sim \phi$) and put down B function in third column.

(11) Add the two B functions in the third column. This gives the A function of the altitude. The value of the altitude is not needed in azimuth determination unless it is desired to use as a check of the field notes.

(12) Enter table with this A function and put down its equivalent B function in the fourth column.

(13) Subtract the B function in the fourth column from the A function.

(14) This gives the A function of the bearing angle of the celestial body east or west of north depending on whether the LHA is east or west.

(15) The remainder of the problem is the same as in the formula solution, that of obtaining the azimuth of body and combining it with the angle to the mark and the grid divergence to obtain the grid azimuth of the mark.

h. The sun problem solved in paragraph 43 is repeated here using the Ageton tables without interpolation; that is, using only the nearest one minute to enter the tables. It is believed that this gives the degree of accuracy required in the field. It is interesting to note how very closely this computation agrees with the determination made in paragraph 43 using seven-place logarithms and the tangent formula.

i. Examples of computation.

Solar observation (Ageton tables)

(Azimuth determination)

Station: 4.	Longitude: 76°18.4′.	Date: 6 Oct. 1941.
S: Sun.	Latitude: 37°00.0′.	Place: Ft. Monroe, Va.
Mark: Sta. A.	Watch: Slow 38 sec.	Name:

Hour angles	1st set			2d set			3d set		
	°	′	″	°	′	″	°	′	″
Time of observation (0-24 hrs.)	8	27	38	8	42	22	8	57	31
Watch correction			38			38			38
Corrected time of observation	8	28	16	8	43	00	8	58	09
Time difference Greenwich 75th M	+5			5			5		
Greenwich civil time of observation	13	28	16	13	43	00	13	58	09

	1st set		2d set		3d set	
	°	′	°	′	°	′
Greenwich H. A. (almanac) 6 Oct	2	56.9	2	56.9	2	56.
Correction (hrs. & mins.)	22	00.0	25	45.0	29	30.9
Correction (seconds)		4.0				2.0
GHA (time of observation)	25	00.9	28	41.9	32	29.3
Longitude: W (−) E (+)	−76	18.4	−76	18.4	−76	18.2
LHA (−) or (+)	51	17.5	47	36.5	43	49.4
						2

To find LHA, add GHA and longitude algebraically, subtract 360° if necessary. If LHA is greater than 180° use: 360°−LHA.

Rules—1. Give K same sign as declination (d); 2. Combine K & ϕ (K$\sim\phi$); add if different signs; difference if same signs.

Bearings: Angle	Bearings: Add	Subtract	Add	Subtract
LHA 51° 17.5′	A 10,772			
d −5 05.7	B 172	A 105,155		
	A 10,944	B 20,121	B 20,121	A 10,944
	K= −8°06.8′	A 85,034		
	ϕ 37°00.0′	K$\sim\phi$= 45°06.8′	B 15,137	
		h=	A 35,258	B 4,767
LHA 47 36.5	A 13,162		β_1= 119°50.4′	A 6,177
d −5 05.8	B 172	A 105,141		
	A 13,334	B 16,931	B 16,931	A 13,334
	K= −7°32.3′	A 88,210		
	ϕ= 37°00.0′	K$\sim\phi$= 44°32.3′	B 14,705	
		h=	A 31,636	B 5,759
LHA 43 49.2	A 15,964		β_2= 122°52.0′	A 7,575
d −5 06.2	B 173	A 105,085		
	A 16,137	B 14,018	B 14,018	A 16,137
	K= −7°03.3′	A 91,067		
	ϕ= 37°00.0′	K$\sim\phi$= 44°03.3′	B 14,347	
		h=	A 28,365	B 6,858
			β_3= 126°08.1′	A 9,279

Grid azimuth: Bearing is WEST if LHA is (+); EAST if LHA is (−).

	°	′	″	°	′	″	°	′	″
Bearing (β) East or West	119	50	24	122	52	00	126	08	06
True azimuth to S	119	50	24	122	52	00	126	08	06
Average angle to mark	−93	42	00	−96	43	30	−100	00	00
True azimuth to mark	26	08	24	26	08	30	26	08	00
Mean true azimuth to mark							26	08	18
Grid divergence						+	1	59	10
Grid azimuth to mark							28	07	28

Polaris observation (Ageton tables)

(Azimuth determination)

Station: A.	Longitude: 76°18′24″.	Date: 6 Oct. 1941.
S: Polaris.	Latitude: 37°00′00″.	Place: Ft. Monroe, Va.
Mark: Bug light.	Watch: Fast 6 sec.	Name:

Hour angles	1st set			2d set			3d set		
	°	′	″	°	′	″	°	′	″
Time of observation (0-24 hrs.)	19	43	09	19	46	59	19	49	16
Watch correction			−06			−06			−06
Corrected time of observation	19	43	03	19	46	53	19	49	10
Time difference Greenwich	5			5			5		
Greenwich civil time of observtion, Oct. 7	0	43	03	0	46	53	0	49	10

	1st set		2d set		3d set	
	°	′	°	′	°	′
Greenwich H. A. (Almanac)	348	56. 3	348	56. 3	348	56. 3
Correction (hrs. & mins.)	10	46. 8	11	31. 9	12	17. 0
Correction (seconds)		0. 8		13. 3		2. 5
GHA (time of observation)	359	43. 9	360	41. 5	361	15. 8
Longitude: W(−) E(+)	−76	18. 4	−76	18. 4	−76	18. 4
LHA (−) or (+)	283	25. 5	284	23. 1	284	57. 4

To find LHA, add GHA and Longitude algebraically, subtract 360° if necessary.
If LHA is greater than 180° use: 360°−LHA.
Rules—1. Give K some sign as declination (d); 2. Combine K & ϕ (K$\sim\phi$); add if different signs; difference if same signs.

Bearings: Angle		Bearings: Add		Subtract		Add		Subtract	
LHA	76° 34.5′	A	1,203						
d	+88 59. 1	B	175,169	A	6. 8				
		A	176,372	B	6. 5	B	6	A	176,372
		K=	89° 48′	A	. 3				
		ϕ	37° 00. 0′	K$\sim\phi$=	52° 48′	B	21,853		
				h=		A	21,859	B	9,876
LHA	75 36. 9	A	1,383			β_1=	1° 14. 5′	A	166,496
d	+88 59. 1	B	175,169	A	6. 8				
		A	176,552	B	6. 4	B	6	A	176,552
		K=	89° 45′	A	. 4				
		ϕ=	37° 00. 0′	K$\sim\phi$=	52° 45′	B	21,803		
				h=		A	21,809	B	9,905
LHA	75° 02. 6′	A	1,497			β_2=	1° 14. 1′	A	166,647
d	+88 59. 1	B	175,169	A	6. 8				
		A	176,666	B	6. 4	B	6	A	176,666
		K=	89° 45′	A	. 4				
		ϕ=	37° 00. 0′	K$\sim\phi$=	52° 45′	B	21,809		
				h=		A	21,815	B	9,902
						β_3=	1° 13. 9′	A	166,764

Grid azimuth: Bearing is WEST if LHA is (+); EAST if LHA is (−)

	°	′	″	°	′	″	°	′	″
Bearing (β) East or West	1	14. 5	----	1	14. 1	----	1	13. 9	----
True azimuth to S	1	14. 5	----	1	14. 1	----	1	13. 9	----
Average angle to mark	77	00. 5	----	77	00. 5	----	77	02. 9	----
True azimuth to mark	78	15. 0	----	78	14. 6	----	78	16. 8	----
Mean true azimuth to mark							78	15. 5	----
Grid divergence							1	59. 2	----
Grid azimuth to mark							80	14. 7	----

Section IX

DUTIES OF RECONNAISSANCE OFFICERS

45. General.—*a.* A reconnaissance officer is a member of the staff of the commander of a mobile artillery unit. At present, reconnaissance officers are assigned—

(1) To each 155-mm artillery regiment, as follows: one to each battalion headquarters battery and one to each firing battery.

(2) To a railway artillery regiment, as follows: one assigned to regimental headquarters battery, one to each battalion headquarters battery and one to each firing battery.

b. The only reconnaissance officer in an antiaircraft regiment is the battalion reconnaissance officer assigned to the battalion headquarters battery of each antiaircraft gun battalion. This officer is the chief assistant to the battalion commander of the mobile gun battalion in carrying out the latter's reconnaissance duties.

46. Reconnaissance detail.—The personnel necessary for the performance of the orientation work will be obtained from the reconnaissance detail of the unit concerned. In general, this detail will consist of the master gunner, observers, spotters, readers, and plotting room men. Some of these are listed as instrument men in tables of organization. During the orientation work either a part or the whole reconnaissance detail (depending on the men available) will be organized into a transit traverse party and will complete the orientation under supervision of the reconnaissance officer. After the orientation is complete, they will establish and operate the observation stations and plotting room. In this chapter we are concerned only with their organization into a transit traverse party. There will usually be available at least nine men for this party which will be organized as follows: one chief of section (master gunner when available), one instrument man, one recorder, two chainmen, two rodmen, and two computers. This party must be carefully trained and must be available whenever needed. If distances are being measured by stadia the two chainmen may be omitted from this party.

47. Orientation duties of a battalion reconnaissance officer.—*a.* The orientation duties of a battalion reconnaissance officer

of 155-mm and railway artillery include the determination of the grid coordinates of all battalion observation posts, all battery directing points, all battery observing stations, the establishment of an orienting line for each, and the computation of the length and azimuth of the battalion baseline, when bilateral observation is used.

b. The battery positions and observing stations having been selected on the ground, the battalion reconnaissance officer plots their approximate positions on a map and formulates a general plan for determining the grid coordinates and orienting lines.

c. In order to determine these data, the coordinates of one or more points in the vicinity must be known. Such known points are used as a basis for the determination of the grid coordinates of other points in that locality. The United States Coast and Geodetic Survey furnishes descriptive data called "description of stations" on the triangulation systems in various regions. They also furnish the latitude and longitude of each triangulation point. In this connection, AR 100–15 states that, "No standard military map on a scale of less than 1:62,500 will be regarded as complete unless at least three geodetic monuments have been erected in every 15-minute quadrangle mapped. On maps of 1:20,000 scale, or greater, except in extensive swamp areas or areas of heavy timber without roads, geodetic monuments or other accurately located physical objects will be so located that no points in the area mapped will be more than two miles from such monument or object." The data describing the location and giving the geographic coordinates of these known points should be obtained by the regimental reconnaissance officer for the areas in which his regiment expects to operate. These tables may be secured through the Chief of Engineers or application may be made direct to the Director of the Coast and Geodetic Survey, Washington, D. C., for a "description of stations" located in the vicinity.

d. The battalion reconnaissance officer studies the geodetic data available, notes the location of all geodetic monuments or other known points in the area and determines which (if any) of these points are reasonably available as starting points for his work. The selection of a starting point will be influenced not only by its proximity to the points whose coordinates he must determine, but also by the visibility of other known points from it. Whenever possible he should select a starting point from which another known point is visible even if it increases the length of his transit traverse, because such a selection simplifies the determination of azimuth.

e. If no known points are available in the area it may be necessary to assume some local plane coordinates. In this system, a well defined and permanent point in the region is arbitrarily designated by the reconnaissance officer as an origin of coordinates, and a true north is determined in this vicinity by astronomical observation. Coordinates are arbitrarily assigned to the origin with values large enough to prevent the occurrence of negative values; $X=100{,}000$ and $Y=200{,}000$ are usually satisfactory.

f. The battalion reconnaissance officer, having selected a starting point (or points), studies the terrain and determines the best method of locating each point whose coordinates are desired; that is, by traverse, resection, or intersection. The traverse method normally will be used. Frequently, intersection may be used in connection with a transit traverse to locate points distant from the traverse route. He selects the most favorable route for his traverse and decides whether to have it close on itself or on some other known point.

g. Throughout his work the reconnaissance officer should constantly bear in mind the importance of speed. A battery is never ready for action until its elements have been oriented. The time when a battery is ready to open effective fire depends rather on the time it takes to establish the communication net and complete the orientation than on the time consumed in moving into position. Therefore, the reconnaissance officer should organize his section so that the field work can be completed and the computations made as rapidly as possible. Whenever possible the computation of field notes should proceed concurrently with the field work. This is entirely practicable if the azimuth has been established at the beginning of the traverse.

h. If there is no known point visible from the starting point, it will be necessary to determine the initial azimuth by taking an astronomical observation by one of the methods outlined in section VIII.

i. In an emergency when circumstances prevent the determination of an initial grid azimuth, the reconnaissance officer should establish at the starting point an arbitrary line as grid south or north, and proceed with his traverse and computation. Such a situation would exist when there are no intervisible known points in the area, or adverse weather conditions prevent the determination of grid azimuth. The computed data, although based on an assumed azimuth, will be accurate for fire control purposes. The orientation of all batteries of the battalion should be based on the same data, so that if one or more base end or observation stations are put out

of action, a rapid shift to other base lines will be facilitated. However, when operating with or near other organizations which are equipped with military grid maps, the reconnaissance officer should determine grid north by taking an astronomical observation when the weather permits, and then convert his local plane coordinates and azimuth from the temporary system to the grid system in the manner described previously in this text.

j. Having thoroughly studied the problem, the battalion reconnaissance officer outlines his plans to the battery reconnaissance officers and apportions the work among the traverse parties under his control.

k. He supervises all the work, including the computations, and as soon as possible turns over to the battery commanders the information needed for the orientation of their batteries. The computation of the battery base lines is a battery responsibility.

l. If the battalion is operating in a harbor defense, he must tie-in his grid coordinates with the system already established in the harbor defense.

m. (1) The amount of orientation accomplished by the reconnaissance officer of an *antiaircraft gun battalion* will normally depend on whether the battalion is being employed in a moving or stable situation. If the battalion is moving, time is usually so limited that it is not practicable to survey a base line for spotters. In such a situation the location of the batteries will generally be obtained from the map and an orienting line established by compass for each battery position. No error in firing data will result if the assumption of an azimuth is approximate, provided all elements of the firing battery are based on the same orientation. If the director is to be located at a considerable distance from the guns, the reconnaissance officer will measure the parallax accurately and establish an orienting line for the director as well as for the guns. When the two-station altimeter is used, orientation of each altimeter is necessary. If the stations are not intervisible, this will require the grid coordinates of each station, and accurate azimuths of the altimetric base-line and datum point from each station.

(2) In a stable situation the battalion reconnaissance officer, assisted by the battery range officers and reconnaissance details, will locate battery positions, directors (if parallax exists), altimetric stations, when used, spotting stations, battalion observation posts, and establish an orienting line for each.

n. In a harbor defense the artillery engineer performs the duties of a reconnaissance officer.

48. Battery reconnaissance officer.—*a.* (1) The range officer also may be the battery reconnaissance officer. He is an assistant to the battalion reconnaissance officer in the initial stages of the orientation work and as such represents the battery commander in the selection of the exact positions for the observing and spotting stations of his battery.

(2) When he and his reconnaissance detail have been released by the battalion reconnaissance officer, he will compute, from the data furnished him, the base-line length and azimuth, the data necessary to locate the battery directing point on the plotting board, and the gun differences.

(3) He is responsible for the training of the battery reconnaissance detail. He must be thoroughly familiar with the contents of this manual and, in case of separate battery action, must be able to complete all the orientation for the proper functioning of his battery.

b. The orientation duties of a battery executive consist of the actual orientation of his guns. That is, he adjusts the azimuth indicating devices of his guns to read a known azimuth when the axes of the bores of the guns are pointed at that azimuth.

c. Battery officers.—Although it has been assumed above that the battalion reconnaissance officer will direct the orientation work for the batteries, it is essential that every battery officer understand the fundamentals of orientation and be prepared, in an emergency, to orient the battery and its observation stations without depending on outside assistance.

49. Solution of an orientation problem.—The following problem illustrates a possible procedure for the reconnaissance officer of a battalion of 8-inch railway artillery:

a. The battalion commander, accompanied by his battery commanders and reconnaissance officer, makes a reconnaissance and selects the approximate positions for the batteries, their observing stations, and the battalion observation post. On completing this reconnaissance, the battalion commander issues the following verbal instructions to his reconnaissance officer: "You know the location of the positions selected for the battalion observation posts, batteries A and B, and their observing stations. You will determine the coordinates and an orienting line for each of these positions."

b. The reconnaissance officer's procedure upon receiving this order is outlined below in chronological order.

(1) He consults the Geodetic Survey tables and other topographic data on hand for the area in which his battalion is operating and notes the location of all geodetic monuments, triangulation stations,

or other points whose geographic coordinates are known. He decides to use three of the points in the area whose longitude and latitude are given. These points are Triangulation Station No. 17, Church Steeple, and B. M. No. 7 (fig. 9).

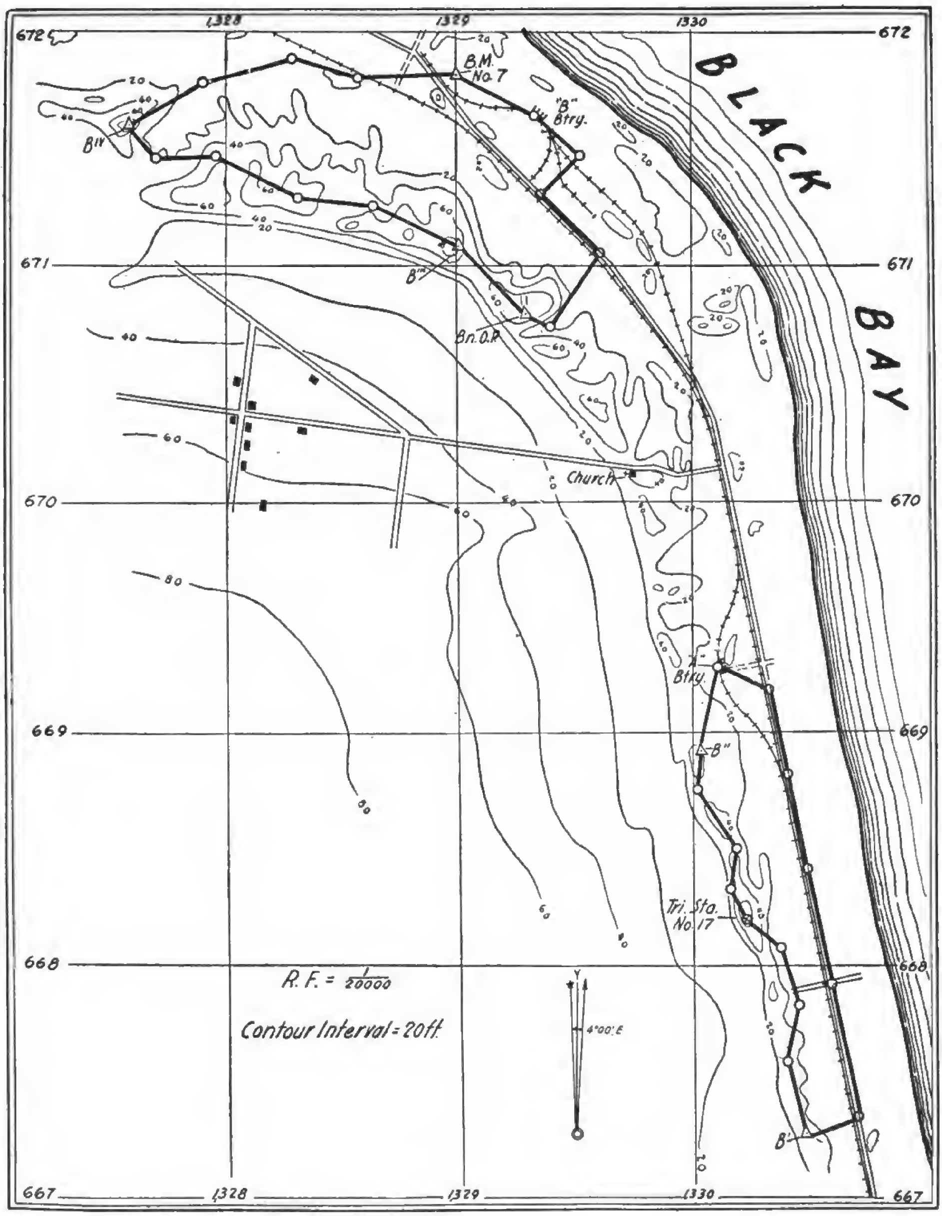

FIGURE 9.

(2) He plots the approximate positions of all points, whose coordinates are desired, on the map as shown in figure 9. B^1 and B^2 are the observing stations for battery A, B^3 and B^4 are the observing stations

for battery B, and *Bn OP* is the observing station for the battalion. The battalion plotting section is using a coincidence range finder, and, therefore, requires no additional observing stations.

(3) He makes a short reconnaissance to determine whether any of the known points are intervisible, and whether all three of the known points are visible from any of the stations he is required to locate. He finds that no known points are visible from B. M. No. 7, but that the church steeple is visible from Triangulation Station No. 17. He also finds that from no station are all three of the known points visible.

(4) Since all three of the known points are not visible from any of the stations he is required to locate, the method of resection cannot be utilized in their location. He makes a careful study of the map and decides to run two closed traverses, the first starting and ending at B. M. No. 7, and the second starting and ending at Triangulation Station No. 17. He also decides to determine azimuth for the first traverse by taking an observation on Polaris at the starting point, and for the second traverse by computing the azimuth of the line joining Triangulation Station No. 17 and the church steeple.

(5) He selects the general routes to be followed by the traverse party.

(6) He assembles the battery reconnaissance officers and the master gunner, outlines the work to be done, and apportions it in such a manner that different parts may be performed concurrently. The traverse parties are instructed to measure distances by stadia.

(7) He supervises the field work of the traverse parties and cautions the parties about establishing azimuths to one or more datum points at each observation station and battery directing point.

c. The battalion reconnaissance officer places one of the battery reconnaissance officers in charge of a computing section which is to operate concurrently with the field parties. The computation is accomplished in the following order:

(1) Geographic coordinates of the three known points are converted into grid coordinates by means of the tables in Special Publications, U. S. Coast and Geodetic Survey (see app. 11).

(2) The true azimuth of the orienting line established at B. M. No. 7 is determined from the data recorded when making the observation on Polaris.

(3) This true azimuth is converted into grid azimuth.

(4) The grid azimuth of the orienting line at B. M. No. 7, determined by observation on Polaris, is compared with that determined

by computation when the traverse was closed. The traverse is then adjusted for error of closure in azimuth.

(5) The first traverse is then computed by the method outlined in paragraph 75, TM 5–235.

(6) The computed coordinates of B. M. No. 7 (computed when the traverse is closed) are compared with its known coordinates and the traverse adjusted for error of closure in distance.

(7) The elevation of points in the traverse is scaled off the map by referring to the contours.

(8) The azimuth of the line Triangulation Station No. 17 to the church steeple is computed from the grid coordinates of these two points.

(9) The remainder of the second traverse is computed in the same manner as that outlined in (4), (5), (6), and (7) above for the first traverse.

d. (1) Upon completion of the computation the reconnaissance officer tabulates the following data:

(*a*) Coordinates, elevation, and orienting line for each battery directing point.

(*b*) Coordinates and orienting line or lines for each observing station and the battalion observation post.

(2) Two copies of these data are distributed to each battery and to the battalion, and one copy is forwarded to the regiment.

e. The battalion reconnaissance officer then releases the battery reconnaissance officers and their traverse parties. The battery reconnaissance officers, under the supervision of their battery commanders, compute the data necessary for the orientation of the plotting boards and complete the organization of the battery plotting rooms and observing stations. The battery executives, utilizing the orienting lines supplied them, orient the guns of their batteries.

APPENDIX I

LIST OF TABLES

1. The following tables will be required in the study of orientation. Page numbers refer to the appropriate table in TM 5–236.

2. The following tables are extracts from the American Nautical Almanac and are required for the proper understanding of problems contained in this manual. Page numbers refer to pages in this manual.

TABLE I

SUN, OCTOBER 1941

G. C. T.	Equation of time	Sun's declination	Sun's GHA
	Monday 6		
h			
0	+11 38.6	−4 52.7	182 54.7
2	11 40.1	4 54.6	212 55.0
4	11 41.6	4 56.6	242 55.4
6	11 43.1	4 58.5	272 55.8
8	11 44.6	5 0.4	302 56.1
10	11 46.0	5 2.3	332 56.5
12	11 47.5	5 4.2	2 56.9
14	11 49.0	5 6.2	32 57.3
16	11 50.5	5 8.1	62 57.6
18	11 51.9	5 10.0	92 58.0
20	11 53.4	5 11.9	122 58.4
22	11 54.9	5 13.8	152 58.7
H. D.	0.7	1.0	......

Corr. to GHA			
Min. or Sec.	Corr. for Minutes	Corr. for 1 hour +Minutes	Corr. for Sec's.
	° ′	° ′	′
0	0 0.0	15 0.0	0.0
1	0 15.0	15 15.0	0.3
2	0 30.0	15 30.0	0.5
3	0 45.0	15 45.0	0.8
4	1 0.0	16 0.0	1.0
5	1 15.0	16 15.0	1.3
6	1 30.0	16 30.0	1.5
7	1 45.0	16 45.0	1.8
8	2 0.0	17 0.0	2.0
9	2 15.0	17 15.0	2.3
10	2 30.0	17 30.0	2.5
11	2 45.0	17 45.0	2.8
12	3 0.0	18 0.0	3.0
13	3 15.0	18 15.0	3.3
14	3 30.0	18 30.0	3.5
15	3 45.0	18 45.0	3.8
16	4 0.0	19 0.0	4.0
17	4 15.0	19 15.0	4.3
18	4 30.0	19 30.0	4.5
19	4 45.0	19 45.0	4.8
20	5 0.0	20 0.0	5.0
21	5 15.0	20 15.0	5.3
22	5 30.0	20 30.0	5.5
23	5 45.0	20 45.0	5.8
24	6 0.0	21 0.0	6.0
25	6 15.0	21 15.0	6.3
26	6 30.0	21 30.0	6.5
27	6 45.0	21 45.0	6.8
28	7 0.0	22 0.0	7.0
29	7 15.0	22 15.0	7.3
30	7 30.0	22 30.0	7.5
31	7 45.0	22 45.0	7.8
32	8 0.0	23 0.0	8.0
33	8 15.0	23 15.0	8.3
34	8 30.0	23 30.0	8.5
35	8 45.0	23 45.0	8.8
36	9 0.0	24 0.0	9.0
37	9 15.0	24 15.0	9.3
38	9 30.0	24 30.0	9.5
39	9 45.0	24 45.0	9.8
40	10 0.0	25 0.0	10.0
41	10 15.0	25 15.0	10.3
42	10 30.0	25 30.0	10.5
43	10 45.0	25 45.0	10.8
44	11 0.0	26 0.0	11.0
45	11 15.0	26 15.0	11.3
46	11 30.0	26 30.0	11.5
47	11 45.0	26 45.0	11.8
48	12 0.0	27 0.0	12.0
49	12 15.0	27 15.0	12.3
50	12 30.0	27 30.0	12.5
51	12 45.0	27 45.0	12.8
52	13 0.0	28 0.0	13.0
53	13 15.0	28 15.0	13.3
54	13 30.0	28 30.0	13.5
55	13 45.0	28 45.0	13.8
56	14 0.0	29 0.0	14.0
57	14 15.0	29 15.0	14.3
58	14 30.0	29 30.0	14.5
59	14 45.0	29 45.0	14.8
60	15 0.0	30 0.0	15.0

TABLE II

GREENWICH HOUR ANGLE OF POLARIS, 1941

For 0^h Greenwich Civil Time

		° ′			° ′			° ′			° ′			° ′			° ′
Jan.	1	74 13.5	Mar.	1	132 39.7	May	1	192 51.3	July	1	252 45.0	Sept.	1	313 33.5	Nov.	1	13 33.6
	2	75 12.9		2	133 39.0		2	193 50.3		2	253 43.8		2	314 32.4		2	14 32.8
	3	76 12.4		3	134 38.4		3	194 49.4		3	254 42.7		3	315 31.3		3	15 32.0
	4	77 11.8		4	135 37.8		4	195 48.4		4	255 41.5		4	316 30.3		4	16 31.1
	5	78 11.2		5	136 37.1		5	196 47.4		5	256 40.3		5	317 29.2		5	17 30.3
	6	79 10.6		6	137 36.4		6	197 46.4		6	257 39.2		6	318 28.1		6	18 29.5
	7	80 10.1		7	138 35.8		7	198 45.4		7	258 38.0		7	319 27.0		7	19 28.7
	8	81 9.5		8	139 35.1		8	199 44.4		8	259 36.8		8	320 25.9		8	20 27.9
	9	82 8.9		9	140 34.5		9	200 43.4		9	260 35.7		9	321 24.8		9	21 27.1
	10	83 8.4		10	141 33.8		10	201 42.4		10	261 34.5		10	322 23.8		10	22 26.3
	11	84 7.8		11	142 33.1		11	202 41.4		11	262 33.3		11	323 22.7		11	23 25.5
	12	85 7.2		12	143 32.4		12	203 40.4		12	263 32.1		12	324 21.6		12	24 24.7
	13	86 6.7		13	144 31.8		13	204 39.4		13	264 31.0		13	325 20.6		13	25 23.9
	14	87 6.1		14	145 31.1		14	205 38.3		14	265 29.8		14	326 19.5		14	26 23.1
	15	88 5.6		15	146 30.4		15	206 37.3		15	266 28.6		15	327 18.5		15	27 22.3
	16	89 5.0		16	147 29.7		16	207 36.3		16	267 27.4		16	328 17.4		16	28 21.6
	17	90 4.5		17	148 29.0		17	208 35.2		17	268 26.3		17	329 16.4		17	29 20.8
	18	91 3.9		18	149 28.2		18	209 34.2		18	269 25.1		18	330 15.3		18	30 20.0
	19	92 3.4		19	150 27.5		19	210 33.1		19	270 23.9		19	331 14.3		19	31 19.3
	20	93 2.8		20	151 26.8		20	211 32.1		20	271 22.8		20	332 13.3		20	32 18.5
	21	94 2.2		21	152 26.1		21	212 31.0		21	272 21.6		21	333 12.2		21	33 17.8
	22	95 1.7		22	153 25.3		22	213 30.0		22	273 20.4		22	334 11.2		22	34 17.1
	23	96 1.1		23	154 24.6		23	214 28.9		23	274 19.2		23	335 10.2		23	35 16.3
	24	97 0.6		24	155 23.8		24	215 27.8		24	275 18.1		24	336 9.2		24	36 15.6
	25	98 0.0		25	156 23.1		25	216 26.8		25	276 16.9		25	337 8.1		25	37 14.9
	26	98 59.5		26	157 22.3		26	217 25.7		26	277 15.7		26	338 7.1		26	38 14.2
	27	99 58.9		27	158 21.6		27	218 24.6		27	278 14.6		27	339 6.1		27	39 13.4
	28	100 58.4		28	159 20.8		28	219 23.5		28	279 13.4		28	340 5.1		28	40 12.7
	29	101 57.8		29	160 20.0		29	220 22.4		29	280 12.2		29	341 4.1		29	41 12.0
	30	102 57.3		30	161 19.2		30	221 21.4		30	281 11.1		30	342 3.1		30	42 11.3
	31	103 56.7		31	162 18.5		31	222 20.3		31	282 9.9	Oct.	1	343 2.1	Dec.	1	43 10.6
Feb.	1	104 56.1	Apr.	1	163 17.7	June	1	223 19.2	Aug.	1	283 8.7		2	344 1.1		2	44 10.0
	2	105 55.6		2	164 16.9		2	224 18.1		2	284 7.6		3	345 0.2		3	45 9.3
	3	106 55.0		3	165 16.1		3	225 17.0		3	285 6.4		4	345 59.2		4	46 8.6
	4	107 54.5		4	166 15.3		4	226 15.9		4	286 5.3		5	346 58.2		5	47 7.9
	5	108 53.9		5	167 14.5		5	227 14.7		5	287 4.1		6	347 57.2		6	48 7.2
	6	109 53.3		6	168 13.6		6	228 13.6		6	288 2.9		7	248 56.3		7	49 6.6
	7	110 52.8		7	169 12.8		7	229 12.5		7	289 1.8		8	349 55.3		8	50 5.9
	8	111 52.2		8	170 12.0		8	230 11.4		8	290 0.6		9	350 54.3		9	51 5.2
	9	112 51.6		9	171 11.2		9	231 10.3		9	290 59.5		10	351 53.4		10	52 4.6
	10	113 51.1		10	172 10.3		10	232 9.1		10	291 58.3		11	352 52.5		11	53 3.9
	11	114 50.5		11	173 9.5		11	233 8.0		11	292 57.2		12	353 51.5		12	54 3.3
	12	115 49.9		12	174 8.6		12	234 6.9		12	293 56.0		13	354 50.6		13	55 2.6
	13	116 49.3		13	175 7.7		13	235 5.8		13	294 54.9		14	355 49.6		14	56 2.0
	14	117 48.8		14	176 6.9		14	236 4.6		14	295 53.7		15	356 48.7		15	57 1.4
	15	118 48.2		15	177 6.0		15	237 3.5		15	296 52.6		16	357 47.8		16	58 0.7
	16	119 47.6		16	178 5.1		16	238 2.3		16	297 51.5		17	358 46.8		17	59 0.1
	17	120 47.0		17	179 4.3		17	239 1.2		17	298 50.3		18	359 45.9		18	59 59.5
	18	121 46.4		18	180 3.4		18	240 0.0		18	299 49.2		19	0 45.0		19	60 58.9
	19	122 45.8		19	181 2.5		19	240 58.9		19	300 48.1		20	1 44.1		20	61 58.2
	20	123 45.2		20	182 1.6		20	241 57.8		20	301 46.9		21	2 43.2		21	62 57.6
	21	124 44.6		21	183 0.7		21	242 56.6		21	302 45.8		22	3 42.3		22	63 57.0
	22	125 44.0		22	183 59.7		22	243 55.5		22	303 44.7		23	4 41.4		23	64 56.4
	23	126 43.4		23	184 58.8		23	244 54.3		23	304 43.5		24	5 40.6		24	65 55.8
	24	127 42.8		24	185 57.9		24	245 53.1		24	305 42.4		25	6 39.7		25	66 55.2
	25	128 42.2		25	186 57.0		25	246 52.0		25	306 41.3		26	7 38.8		26	67 54.6
	26	129 41.5		26	187 56.0		26	247 50.8		26	307 40.2		27	8 37.9		27	68 54.0
	27	130 40.9		27	188 55.1		27	248 49.7		27	308 39.1		28	9 37.1		28	69 53.4
	28	131 40.3		28	189 54.1		28	249 48.5		28	309 38.0		29	10 36.2		29	70 52.8
	29	132 39.7		29	190 53.2		29	250 47.3		29	310 36.8		30	11 35.3		30	71 52.3
	30	133 39.0		30	191 52.3		30	251 46.2		30	311 35.7		31	12 34.5		31	72 51.7
	31	134 38.4		31	192 51.3		31	252 45.0		31	312 34.6		32	13 33.6		32	73 51.1

TABLE III

CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF STARS

Min.	Hours of Greenwich Civil Time								Sec.	Corr.
	0^h	1^h	2^h	3^h	4^h	5^h	6^h	7^h		
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′		′
0	0 0.0	15 2.5	30 4.9	45 7.4	60 9.9	75 12.3	90 14.8	105 17.2	0	0.0
1	0 15.0	15 17.5	30 19.9	45 22.4	60 24.9	75 27.4	90 29.8	105 32.3	1	0.3
2	0 30.1	15 32.5	30 35.0	45 37.5	60 39.9	75 42.4	90 44.9	105 47.3	2	0.5
3	0 45.1	15 47.6	30 50.1	45 52.5	60 55.0	75 57.4	90 59.9	106 2.4	3	0.8
4	1 0.2	16 2.6	31 5.1	46 7.6	61 10.0	76 12.5	91 14.9	106 17.4	4	1.0
5	1 15.2	16 17.7	31 20.1	46 22.6	61 25.1	76 27.5	91 30.0	106 32.5	5	1.3
6	1 30.2	16 32.7	31 35.2	46 37.6	61 40.1	76 42.6	91 45.0	106 47.5	6	1.5
7	1 45.3	16 47.8	31 50.2	46 52.7	61 55.1	76 57.6	92 0.1	107 2.5	7	1.8
8	2 0.3	17 2.8	32 5.3	47 7.7	62 10.2	77 12.6	92 15.1	107 17.6	8	2.0
9	2 15.4	17 17.8	32 20.3	47 22.8	62 25.2	77 27.7	92 30.2	107 32.6	9	2.3
10	2 30.4	17 32.9	32 35.3	47 37.8	62 40.3	77 42.7	92 45.2	107 47.7	10	2.5
11	2 45.5	17 47.9	32 50.4	47 52.8	62 55.3	77 57.8	93 0.2	108 2.7	11	2.8
12	3 0.5	18 3.0	33 5.4	48 7.9	63 10.3	78 12.8	93 15.3	108 17.7	12	3.0
13	3 15.5	18 18.0	33 20.5	48 22.9	63 25.4	78 27.9	93 30.3	108 32.8	13	3.3
14	3 30.6	18 33.0	33 35.5	48 38.0	63 40.4	78 42.9	93 45.4	108 47.8	14	3.5
15	3 45.6	18 48.1	33 50.5	48 53.0	63 55.5	78 57.9	94 0.4	109 2.9	15	3.8
16	4 0.7	19 3.1	34 5.6	49 8.0	64 10.5	79 13.0	94 15.4	109 17.9	16	4.0
17	4 15.7	19 18.2	34 20.6	49 23.1	64 25.6	79 28.0	94 30.5	109 32.9	17	4.3
18	4 30.7	19 33.2	34 35.7	49 38.1	64 40.6	79 43.1	94 45.5	109 48.0	18	4.5
19	4 45.8	19 48.2	34 50.7	49 53.2	64 55.6	79 58.1	95 0.6	110 3.0	19	4.8
20	5 0.8	20 3.3	35 5.7	50 8.2	65 10.7	80 13.1	95 15.6	110 18.1	20	5.0
21	5 15.9	20 18.3	35 20.8	50 23.3	65 25.7	80 28.2	95 30.6	110 33.1	21	5.3
22	5 30.9	20 33.4	35 35.8	50 38.3	65 40.8	80 43.2	95 45.7	110 48.2	22	5.5
23	5 45.9	20 48.4	35 50.9	50 53.3	65 55.8	80 58.3	96 0.7	111 3.2	23	5.8
24	6 1.0	21 3.4	36 5.9	51 8.4	66 10.8	81 13.3	96 15.8	111 18.2	24	6.0
25	6 16.0	21 18.5	36 21.0	51 23.4	66 25.9	81 28.3	96 30.8	111 33.3	25	6.3
26	6 31.1	21 33.5	36 36.0	51 38.5	66 40.9	81 43.4	96 45.8	111 48.3	26	6.5
27	6 46.1	21 48.6	36 51.0	51 53.5	66 56.0	81 58.4	97 0.9	112 3.4	27	6.8
28	7 1.1	22 3.6	37 6.1	52 8.5	67 11.0	82 13.5	97 15.9	112 18.4	28	7.0
29	7 16.2	22 18.7	37 21.1	52 23.6	67 26.0	82 28.5	97 31.0	112 33.4	29	7.3
30	7 31.2	22 33.7	37 36.2	52 38.6	67 41.1	82 43.6	97 46.0	112 48.5	30	7.5
31	7 46.3	22 48.7	37 51.2	52 53.7	67 56.1	82 58.6	98 1.1	113 3.5	31	7.8
32	8 1.3	23 3.8	38 6.2	53 8.7	68 11.2	83 13.6	98 16.1	113 18.6	32	8.0
33	8 16.4	23 18.8	38 21.3	53 23.7	68 26.2	83 28.7	98 31.1	113 33.6	33	8.3
34	8 31.4	23 33.9	38 36.3	53 38.8	68 41.2	83 43.7	98 46.2	113 48.6	34	8.5
35	8 46.4	23 48.9	38 51.4	53 53.8	68 56.3	83 58.8	99 1.2	114 3.7	35	8.8
36	9 1.5	24 3.9	39 6.4	54 8.9	69 11.3	84 13.8	99 16.3	114 18.7	36	9.0
37	9 16.5	24 19.0	39 21.4	54 23.9	69 26.4	84 28.8	99 31.3	114 33.8	37	9.3
38	9 31.6	24 34.0	39 36.5	54 39.0	69 41.4	84 43.9	99 46.3	114 48.8	38	9.5
39	9 46.6	24 49.1	39 51.5	54 54.0	69 56.5	84 58.9	100 1.4	115 3.9	39	9.8
40	10 1.6	25 4.1	40 6.6	55 9.0	70 11.5	85 14.0	100 16.4	115 18.9	40	10.0
41	10 16.7	25 19.1	40 21.6	55 24.1	70 26.5	85 29.0	100 31.5	115 33.9	41	10.3
42	10 31.7	25 34.2	40 36.7	55 39.1	70 41.6	85 44.0	100 46.5	115 49.0	42	10.5
43	10 46.8	25 49.2	40 51.7	55 54.2	70 56.6	85 59.1	101 1.5	116 4.0	43	10.8
44	11 1.8	26 4.3	41 6.7	56 9.2	71 11.7	86 14.1	101 16.6	116 19.1	44	11.0
45	11 16.8	26 19.3	41 21.8	56 24.2	71 26.7	86 29.2	101 31.6	116 34.1	45	11.3
46	11 31.9	26 34.4	41 36.8	56 39.3	71 41.7	86 44.2	101 46.7	116 49.1	46	11.5
47	11 46.9	26 49.4	41 51.9	56 54.3	71 56.8	86 59.2	102 1.7	117 4.2	47	11.8
48	12 2.0	27 4.4	42 6.9	57 9.4	72 11.8	87 14.3	102 16.8	117 19.2	48	12.0
49	12 17.0	27 19.5	42 21.9	57 24.4	72 26.9	87 29.3	102 31.8	117 34.3	49	12.3
50	12 32.1	27 34.5	42 37.0	57 39.4	72 41.9	87 44.4	102 46.8	117 49.3	50	12.5
51	12 47.1	27 49.6	42 52.0	57 54.5	72 56.9	87 59.4	103 1.9	118 4.3	51	12.8
52	13 2.1	28 4.6	43 7.1	58 9.5	73 12.0	88 14.5	103 16.9	118 19.4	52	13.0
53	13 17.2	28 19.6	43 22.1	58 24.6	73 27.0	88 29.5	103 32.0	118 34.4	53	13.3
54	13 32.2	28 34.7	43 37.1	58 39.6	73 42.1	88 44.5	103 47.0	118 49.5	54	13.5
55	13 47.3	28 49.7	43 52.2	58 54.6	73 57.1	88 59.6	104 2.0	119 4.5	55	13.8
56	14 2.3	29 4.8	44 7.2	59 9.7	74 12.2	89 14.6	104 17.1	119 19.5	56	14.0
57	14 17.3	29 19.8	44 22.3	59 24.7	74 27.2	89 29.7	104 32.1	119 34.6	57	14.3
58	14 32.4	29 34.8	44 37.3	59 39.8	74 42.2	89 44.7	104 47.2	119 49.6	58	14.5
59	14 47.4	29 49.9	44 52.4	59 54.8	74 57.3	89 59.7	105 2.2	120 4.7	59	14.8
60	15 2.5	30 4.9	45 7.4	60 9.9	75 12.3	90 14.8	105 17.2	120 19.7	60	15.0

Table IV

POLARIS, 1941

APPARENT PLACE, TIME OF UPPER CULMINATION, AND TIME INTERVAL BETWEEN UPPER CULMINATION AND ELONGATION EAST OR WEST

The local civil time of culmination on any meridian for a given date is found by taking from the following table the *Civil Time* of the nearest Greenwich culmination and reducing it to the given date by means of the *variation per day,* and to the longitude of the given meridian by means of the *variation per hour.*

The time interval between upper and lower culmination is 12^h diminished by one-half the numerical value of the *variation per day.*

The last column below applies to all meridians.

Civil time		Upper culmination, meridian of Greenwich					Latitude	Mean time interval, elongation minus upper culmination
		Apparent right ascension	Apparent declination	Civil time	Variation per day	Variation per hour		
		h m 1 42	° ′ +88 58					
						W. E.		W. E.
		s	″	h m s	m s	s	°	h m
Jan.	0. 8	127	78. 5	19 3 55	−3 57. 0	−9. 88+	10	+5 58. 3−
	10. 8	115	79. 6	18 24 24	3 57 0	9. 88	12	5 58. 1
	20. 7	103	80. 0	17 44 53	3 57. 1	9. 88	14	5 58. 0
	30. 7	91	79. 9	17 5 22	3 57. 1	9. 88	16	5 57. 8
Feb.	9. 7	79	79. 1	16 25 51	3 57. 0	9. 88	18	5 57. 7
	19. 7	68	77. 7	15 46 20	−3 56. 9	−9. 87+	20	+5 57. 5−
Mar.	1. 6	58	75. 8	15 6 52	3 56. 8	9. 87	22	5 57. 4
	11. 6	50	73. 3	14 27 24	3 56. 6	9. 86	24	5 57. 2
	21. 6	44	70. 5	13 47 59	3 56. 4	9. 85	26	5 57. 0
	31. 5	40	67. 5	13 8 36	3 56. 2	9. 84	28	5 56. 8
Apr.	10. 5	38	64. 4	12 29 16	−3 56. 0	−9. 83+	30	+5 56. 7−
	20. 5	39	61. 2	11 49 57	3 55. 7	9. 82	32	5 56. 5
	30. 5	42	58. 2	11 10 41	3 55. 5	9. 81	34	5 56. 2
May	10. 4	47	55. 4	10 31 27	3 55. 3	9. 80	36	5 56. 0
	20. 4	54	52. 9	9 52 15	3 55. 1	9. 80	38	5 55. 8
	30. 4	62	50. 8	9 13 4	−3 55. 0	−9. 79+	40	+5 55. 6−
June	9. 4	72	49. 1	8 33 55	3 54. 9	9. 79	42	5 55. 4
	19. 3	83	48. 0	7 54 47	3 54. 8	9. 78	44	5 55. 1
	29. 3	95	47. 4	7 15 39	3 54. 7	9. 78	46	5 54. 8
July	9. 3	107	47. 3	6 36 33	3 54. 6	9. 78	48	5 54. 5
	19. 2	120	47. 7	5 57 26	−3 54. 6	−9. 78+	50	+5 54. 2−
	29. 2	132	48. 7	5 18 19	3 54. 7	9. 78	52	5 53. 8
Aug.	8. 2	144	50. 2	4 39 12	3 54. 7	9. 78	54	5 53. 4
	18. 2	155	52. 2	4 0 4	3 54. 8	9. 78	56	5 53. 0
	28. 1	166	54. 6	3 20 55	3 54. 9	9. 79	58	5 52. 5
Sept.	7. 1	175	57. 4	2 41 46	−3 55. 0	−9. 79+	60	+5 52. 0−
	17. 1	183	60. 5	2 2 34	3 55. 2	9. 80	62	5 51. 4
	27. 1	189	63. 8	1 23 22	3 55. 3	9. 80	64	5 50. 7
Oct.	7. 0	194	67. 4	0 44 8	3 55. 5	9. 81−	66	5 49. 9
	17. 0	198	71. 1	0 4 52	3 55. 7	9. 82	68	5 49. 0
	26. 9	199	74. 9	23 25 34	−3 55. 9	−9. 83+	70	+5 47. 9−
Nov.	5. 9	198	78. 6	22 46 14	3 56. 1	9. 84		
	15. 9	195	82. 2	22 6 52	3 56. 3	9. 85		
	25. 9	191	85. 5	21 27 28	3 56. 5	9. 85		
Dec.	5. 9	184	88. 6	20 48 3	3 56. 7	9. 86		
	15. 8	175	91. 2	20 8 35	−3 56. 8	−9. 87+		
	25. 8	166	93. 3	19 29 6	3 56. 9	9. 87		
	35. 8	154	94. 9	18 49 36	−3 57. 0	−9. 88+		

Appendix II

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